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BUILD 1 OF AN ACCELERATED MISSION TEST OF A TF41 WITH BLOCK 76 --ETC(U)
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BUILD 1 OF AN ACCELERATED MISSION TEST OF A TF41 WITH BLOCK 76 HARDWARE

PERFORMANCE BRANCH
TURBINE ENGINE DIVISION

MARCH 1979

TECHNICAL REPORT AFAPL-TR-79-2020
Final Report for Period 18 October 1977 – 13 January 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An accelerated mission test (AMT) of a TF41 (S/N 142163) was conducted in the Air Force Aero Propulsion Laboratory's "D" bay sea level engine test facility between 18 Oct 77 and 13 Jan 78. The primary objective of the test was to evaluate the structural reliability of a series of parts changes known as "Block 76" hardware under realistic usage conditions. A two hundred sixty three hour test program was initially planned but only one hundred and six hours were actually completed due to the failure of a second stage high pressure turbine blade. The second stage turbine had been reworked and the verification → over

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of this rework scheme was a secondary objective of this test. The failure occurred at a reworked location but the actual cause of failure could not be determined. The post-test teardown inspection showed all of the Block 76 hardware to be in good condition.

FOREWORD

This report describes an in-house test conducted by personnel of the Turbine Engine Division and Technical Facilities Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, under project 3066, Task 16, Work Unit 02.

The work reported herein was performed during the period 18 October 1977 to 13 January 1978 under the direction of the project engineer, Robert J. May, Jr. (AFAPL/TBA).

The authors wish to thank the technicians involved for their hard work in this program, especially Messers Richard G. Homer, Paul R. Hagedorn, Jerrold F. Carnes, Leroy P. Sauer, Donald J. Perdzock, and Robert Graf. Special mention goes to Mr Mark Reitz for his aid in data reduction and report preparation. The authors also wish to express their thanks to the Detroit Diesel Allison Division of General Motors especially Mr Darwin Hoose and Mr Gary Williams for their patience and assistance.

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I. INTRODUCTION

This report describes an accelerated mission test (AMT) of a Detroit Diesel Allison TF41-A-1 turbofan engine, S/N 142163. The primary objective of the test was to evaluate the structural reliability under realistic usage conditions of a series of structural improvements known as "Block 76" hardware (see Table 1). This test was conducted as part of a fleet leader program which also included flight test of this engine configuration by both the Navy and Air Force. This test was carried out between 18 October 1977 and 13 January 1978 in the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility. Two hundred sixty three hours of AMT testing were initially scheduled for this engine build. However, the test was prematurely terminated after only 106 hours due to the failure in the second stage high pressure turbine (HPT-2).

Table 1 "Block 76" Hardware

Part	Purpose
HPT #6 cast bearing support	Ease of Assembly and Reduced Oil Consumption
HPT - 1 cast blade	Reduce cost
HPT - 1 bullnose vanes	Obtain 500 hour hot section life
#5 bearing rear seal	Deletes seal requirement
HPC-4-5-6 Eiffel tower vanes	Improve fatigue strength
HPC - 1 full chord blade	Improve surge margin
8-9 fuel manifold	Improve temperature profile
NL anticipator	Reduce turbine inlet temperature spikes
HPT - 1 lockplate damper	Reduce fretting
Viton Wills ring	Reduce oil consumption

II. TEST OBJECTIVES

<u>OBJECTIVE 1</u>: Establish durability and operability characteristics of a TF41 with "Block 76" hardware modifications under realistic usage conditions.

In the past, several TF41 fixes and modifications were introduced into the fleet without proper testing and evaluation. These hastily adopted fixes, in addition to not solving the problems they were intended to, have resulted in unexpected interactions which have caused failures in other components. By the time these problems surface, the entire fleet has been retrofit and the purging process is time consuming and causes related non-technical problems. According to the 1975 TF41 Executive Review Group Report (Ref. 1), "this issue can be resolved by designing <u>proper</u> test programs to prove the improved parts are really improved." The report further states that the consequences of the proposed fixes should be demonstrated in the context of the total engine and under realistic usage conditions. This test objective is aimed at meeting this ERG recommendation by running a production TF41, modified with the proposed "Block 76" hardware, through a test program which is representative of the type of usage that the engine will see in the field. The "Block 76" hardware modifications and their purpose are described in Table 1.

<u>OBJECTIVE 2</u>: Demonstrate the durability of the proposed second stage high pressure turbine (HPT-2) wheel serration teeth rework.

Second stage high pressure turbine wheels with crack indications on the face and extending along the root radius were first reported in mid-1976. Exhibits were returned to Allison who determined the cause was handling damage during overhaul. A recent review at the Navy's Jacksonville overhaul facility showed that 2/3 of the HPT-2 wheels have this problem. The Air Force is experiencing similar

handling damage, although apparently to a lesser extent. A recent TF41 Management Review Group Meeting highlighted this handling damage as a major TF41 problem area.

Allison has proposed a short term solution which consists of a blending rework of the damaged teeth (Figure 1). (The long term solution includes major structural changes, which if accepted will not be ready for several years). A reworked turbine wheel has been run through 52 hours of AMT testing and 48 hours of resonance testing for the initial clearance of this rework procedure. The initial release of this rework allows a maximum of 250 hours service life. In keeping with the 1975 TF41 Executive Review Group's mandate that "there must be very careful testing and verification of the adequacy of repair procedures for the critical hot section of the engine", (Ref. 1) this rework procedure will be verified in this 263 hour AMT test to extend the rework time limit from 250 hours to 450 hours.

<u>OBJECTIVE 3</u>: Document overall engine performance deterioration.

The 1974 TF41 Executive Review Group (Ref. 2) listed engine thrust deterioration as a problem area. However, the engines in the field have been seeing less than 200 hours of use before overhaul due to assorted durability problems. In this relatively short amount of time, the engines have not deteriorated to the point of causing a problem. However, many of the CIP objectives, including the "Block 76" hardware modifications, are aimed at improving engine life to the point where the TF41 is a "firm 1000 hour MOT engine with a 500 hour hot section periodic inspection." Under these conditions, deterioration is expected to become a problem. A recent TF41 Management Review Group established engine thrust deterioration as a prime area of concern.

Some deterioration data has been generated by past AEDC tests of TF41s. However, the engines did not have the "Block 76" hardware modifications which may impact the engine's deterioration characteristics. More importantly, due to the nature of the test objectives, most of the AEDC engine's test time was at steady

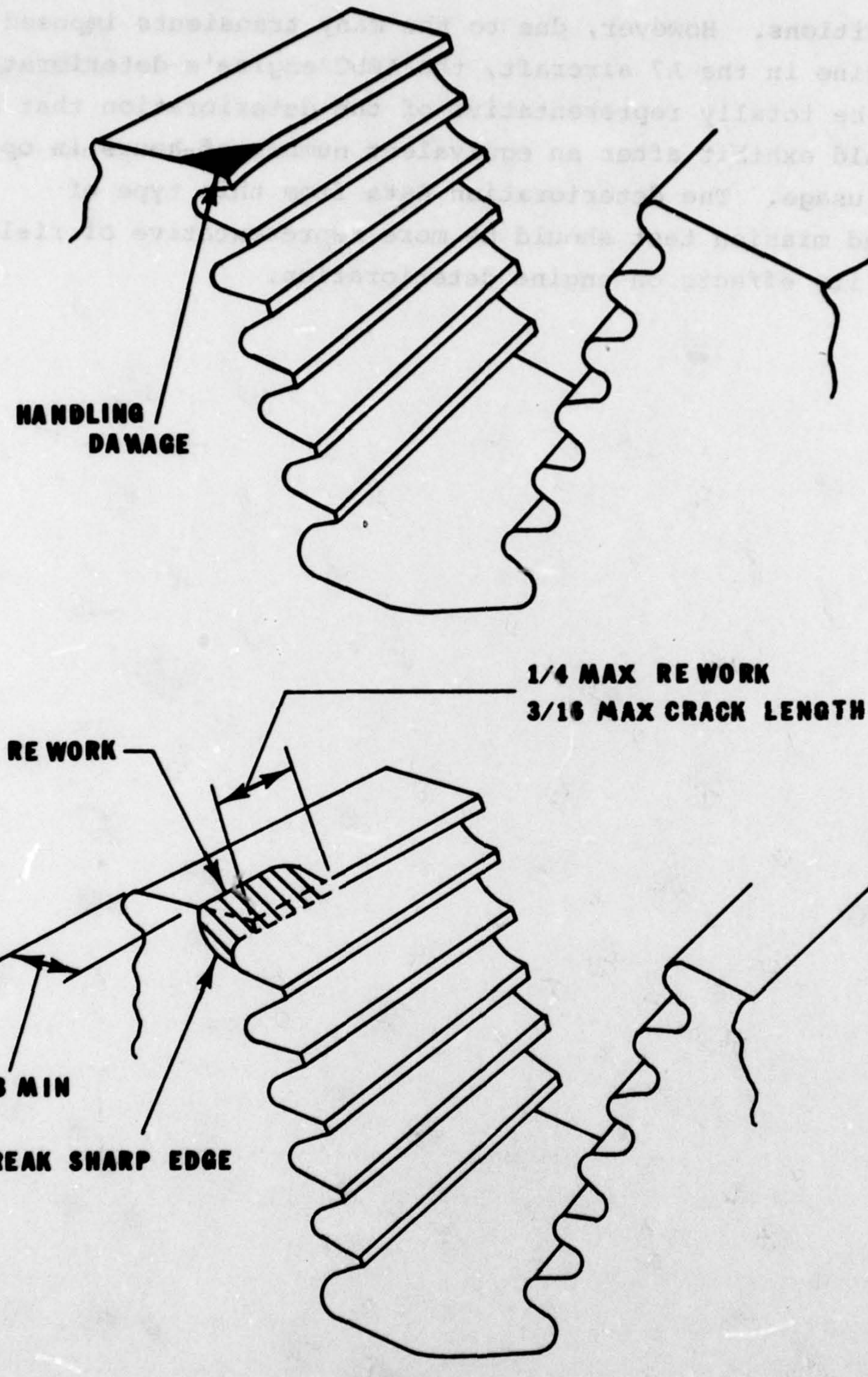


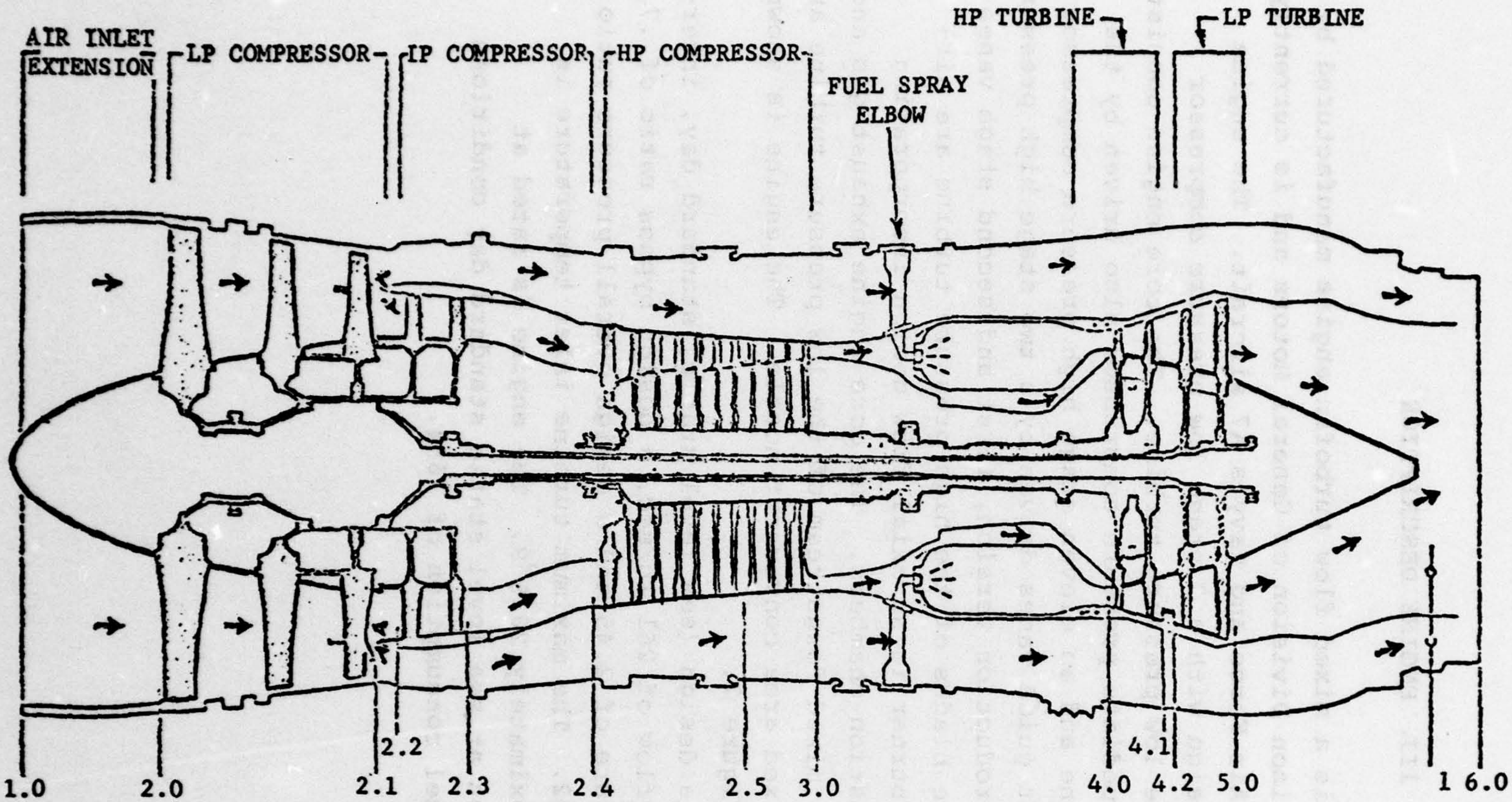
Figure 1 HPT-2 Wheel Handling Damage and Proposed Rework

state conditions. However, due to the many transients imposed on the engine in the A7 aircraft, the AEDC engine's deterioration would not be totally representative of the deterioration that an engine would exhibit after an equivalent number of hours in operational usage. The deterioration data from this type of accelerated mission test should be more representative of field usage and its effects on engine deterioration.

III. ENGINE DESCRIPTION

The TF41-A-1 is a mixed flow turbofan engine manufactured by Detroit Diesel Allison Division of General Motors and is currently used to power the Air Force and Navy's A7 aircraft. The engine is a twin spool design with a 3 stage low pressure compressor driven by a 2 stage low pressure turbine. The core engine consists of a 2 stage intermediate pressure compressor also driven by the low pressure turbine and an eleven stage high pressure compressor with variable inlet guide vanes driven by a two stage high pressure turbine. In the production version, first and second stage vanes and the first stage blades of the high pressure turbine are air-cooled. The main burner is an axial flow design incorporating ten cannular combustion chambers. The core engine exhaust gas and the bypass air are mixed downstream of the low pressure turbine and exhausted out a fixed area convergent nozzle. The engine is shown schematically in Figure 2.

The TF41 has a design (sea level static, standard day, intermediate power) airflow of 261 lb/sec, a design bypass ratio of .7, a design fan pressure of 2.45 and a design overall pressure ratio of approximately 22. The maximum turbine inlet temperature is estimated at approximately 2625^{o}R. The engine is rated at 14,500 lb of thrust at sea level static standard day conditions with a specific fuel consumption of .654.



1.0 Engine Inlet
2.0 LP Compressor Inlet
2.1 Bypass Duct Inlet
2.2 IP Compressor Inlet
2.3 IP Compressor Outlet

2.4 HP Compressor Inlet
2.5 Seventh Stage Bleed Outlet
3.0 HP Compressor Outlet
4.0 HP Turbine Inlet
4.1 HP Turbine Outlet

4.2 LP Turbine Inlet
5.0 LP Turbine Outlet
5.1 Measured Gas Pressure and Temperature Station
6.0 Engine Outlet

Figure 2 TF41 Engine Schematic

IV. FACILITY DESCRIPTION

BACKGROUND

Building 71A was originally constructed during World War II as a large reciprocating engine test facility. The basic structure consisted of four straight-through, square cross section, reinforced concrete test cells. The cross sectional area was nominally 2500 square feet in a 50 feet by 50 feet distribution. The test cells were siamesed in two pairs, each pair sharing one common wall along their entire length.

In 1951, Test Cells C and D were converted to support the testing of gas turbine engines. This was done through the addition of a large vertical chimney on the cell inlet and exhaust; thus, making these cells into a conventional "U" shaped configuration.

In 1975, a major Military Construction Program modernized one of these two jet test cells, Test Cell D. This modernized facility is discussed in the following sections (Figure 3).

BASIC CAPABILITIES

"D"-Bay utilizes a floor mount system for engine installations. The thrust bed is rectangular in shape and utilizes a hinge type flexure at each corner. Maximum thrust load rating is 60,000 pounds and is measured via an Ormand, constant temperature load cell. The constant temperature is maintained through a recirculating glycol system with self-contained heater elements. The load cell is capable of measuring both forward and reverse thrust.

The physical size of engines which can be operated in "D"-Bay is limited to 8'-4" in diameter and 20 feet in length. Engine and mounting hardware combined total weight must stay below 35,000 pounds. In addition, the total weight of any given single piece

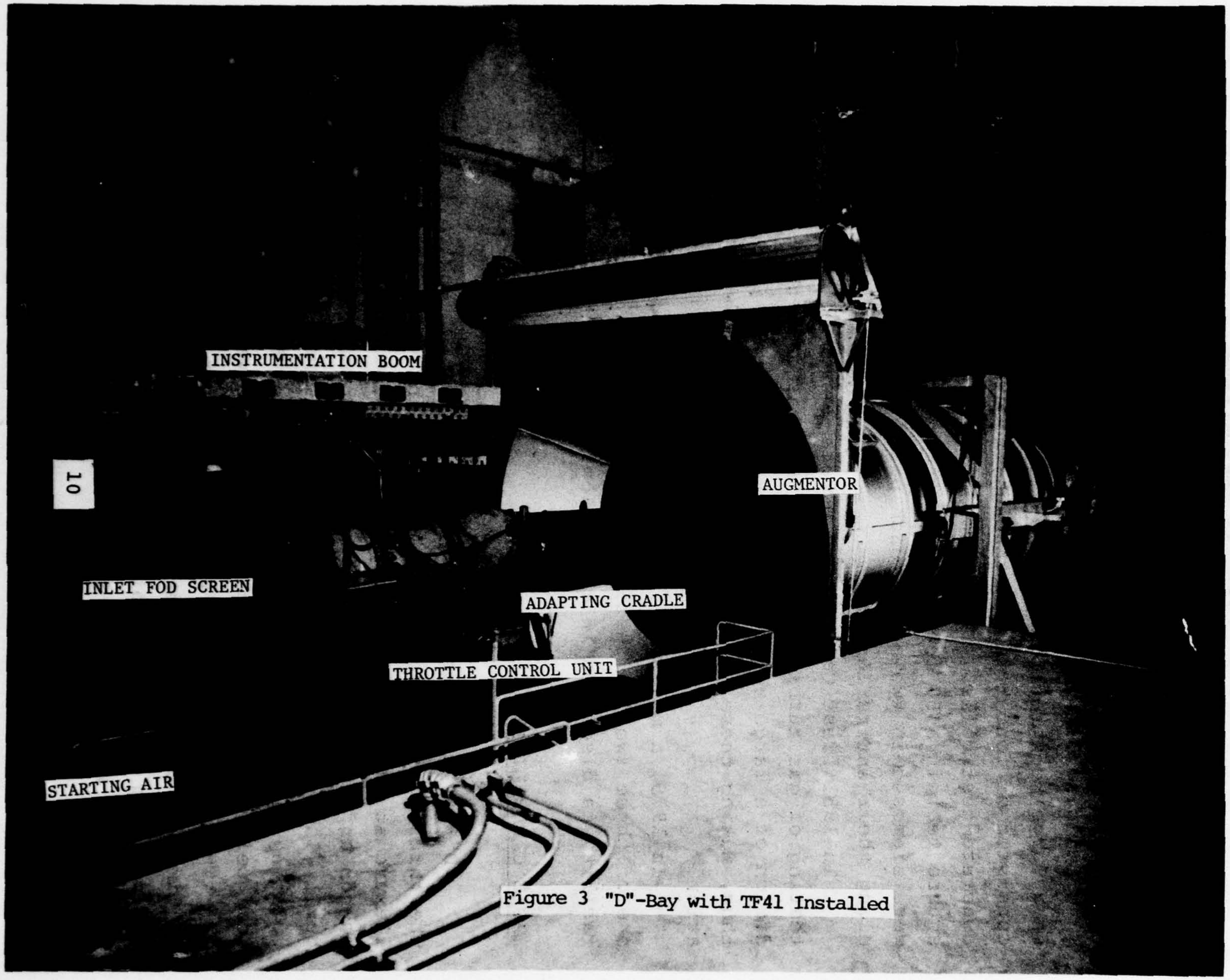


Figure 3 "D"-Bay with TF41 Installed

must be less than 5 tons due to the load limitation on the test cell bridge cranes.

The floor mounted, pedestal type thrust bed is composed of three large steel frames. These consist of (1) the base or fixed frame, (2) the thrust frame (or "live" frame), and (3) the engine mounting frame. The engine mounting frame is permanently attached to the thrust frame and contains a series of regularly spaced holes on its upper surface to facilitate the attachment of an engine adapting cradle.

The engine adapting cradle is a device which must be uniquely designed for every engine type. The AFAPL currently has an inventory of cradles which will support the TF-41, TF-34, F-100, TF-30 and the J-57. This cradle acts as the primary member for transmission of the engine thrust load into the thrust frame. An additional purpose is to adjust the vertical height of the engine centerline so that it matches the centerline of the cell augmentor.

Test Cell Air Flow

"D"-Bay has a conventional U-shaped, flow path for primary engine test air. Air is drawn down vertically through the inlet and then passes through a set of turning vanes and a large mesh bird screen. Behind the engine, air is processed down a 11' diameter test cell augmentor and blast suppressor entering a large square plenum chamber. Located directly above the pleneum chamber is a large vertical chimney which contains 42 tubular shaped mufflers for suppressing the noise level of the exiting exhaust flow. The test cell airflow design point is 2300 pounds per second with less than five inches of water inlet pressure drop. Higher airflows are possible, assuming greater inlet depression is tolerable by the test requirements.

Test cell air augmentation has been shown to be considerable, allowing cooling of the exhaust gas from the TF-41 to below 300^{o}F prior to reaching the blast suppressor. The exhaust stack soundproofing has a 750^{o}F limitation and water cooling is available, if required. In order to provide capability for adjustment of the

augmentor to tailpipe distance, once the engine is installed, the augmentor will traverse approximately 10 feet. It does this through a rail/roller system and is actuated by a hydraulic motor.

Fuel Supply System

Fuel storage is handled by the AFAPL centralized Fuel Farm. This provides about 800,000 gallons of fuel which can be routed to the test cell from 32-25,000 gallon tanks. The large number of tanks provides flexibility in choosing the type of fuel used in any given test, and tanks may be selected from the test cell.

Fuel is delivered from the farm to the test cell through several stages of filtration. Basic pipe sizes are large enough to accommodate a flow rate in excess of 100,000 pounds-per-hour. The principal purpose of the in-cell fuel system, however, is to provide transient flow rate capability. Due to the remote location of the storage facilities, a system of cell pumps and accumulators was designed to provide a 100,000 pph/sec. transient flow rate capability. In this system, fuel is delivered to the fuel accumulator from the cell boost pump through a level control valve which maintains fuel level in the accumulator. Under low usage conditions, excess fuel is recirculated back to the boost pump inlet by a backpressure control valve. In order to prevent heat build-up in the recirculated fuel, a portion of it is routed to a heat exchanger where it is cooled prior to re-mixing with the main stream. Cooling water flow through the heat exchanger is automatically controlled in accordance with fuel temperature. The entire system is monitored and controlled by the digital process control computers.

Fuel is routed to the engine test deck via a 4" diameter hard line. Additional fine scale filtration is accomplished directly under the thrust bed and flexible hose is then utilized to finally connect to the engine fuel inlet. The fuel system provides for fuel inlet pressure adjustment over the range of 0 to 100 psig.

Starting Air System

Starting air is delivered to the engine deck by a 6" diameter hard line. This is locally reduced to 4" diameter, then passed under the live bed to a position immediately below the engine mounting frame. Flexible hose is then attached to the engine air starter.

Starting air is supplied by three Ingersol-Rand, Pac-Air 3000 compressors. These will generate approximately 5.4 pounds per second total flowrate at pressures up to 100 psig. Pressure control and compressor anti-surge control is provided by the test cell digital control system. These compressors are equipped with remote start capability so that in the event of an engine emergency, either the computer or the operator could start them from the control room.

Computer

The entire "D"-Bay test faciltiy and the engine are controlled by a Taylor 1010/72 process control computer (see Appendix F for a more detailed description). The 1010 is a direct digital control (DDC), real time processor which interfaces with the engine and facility through a series of analog and digital inputs which provide the computer with the information necessary to regulate, control, and optimize all phases of the "D"-Bay operation. Analog instrumentation signals are converted to a digital count, the computer compares the value with the desired value and then it outputs a signal to initiate the desired control action (Figure 4). This system provides an extra measure of safety during test operations. Each instrumentation signal acquired by the computer is continuously monitored and has a high and low limit associated with it. If the computer detects an out of limits condition it can do any one of three things - notify the operator but take no action, notify the operator and automatically return the engine to idle, notify the operator and shut the engine and facility down completely.

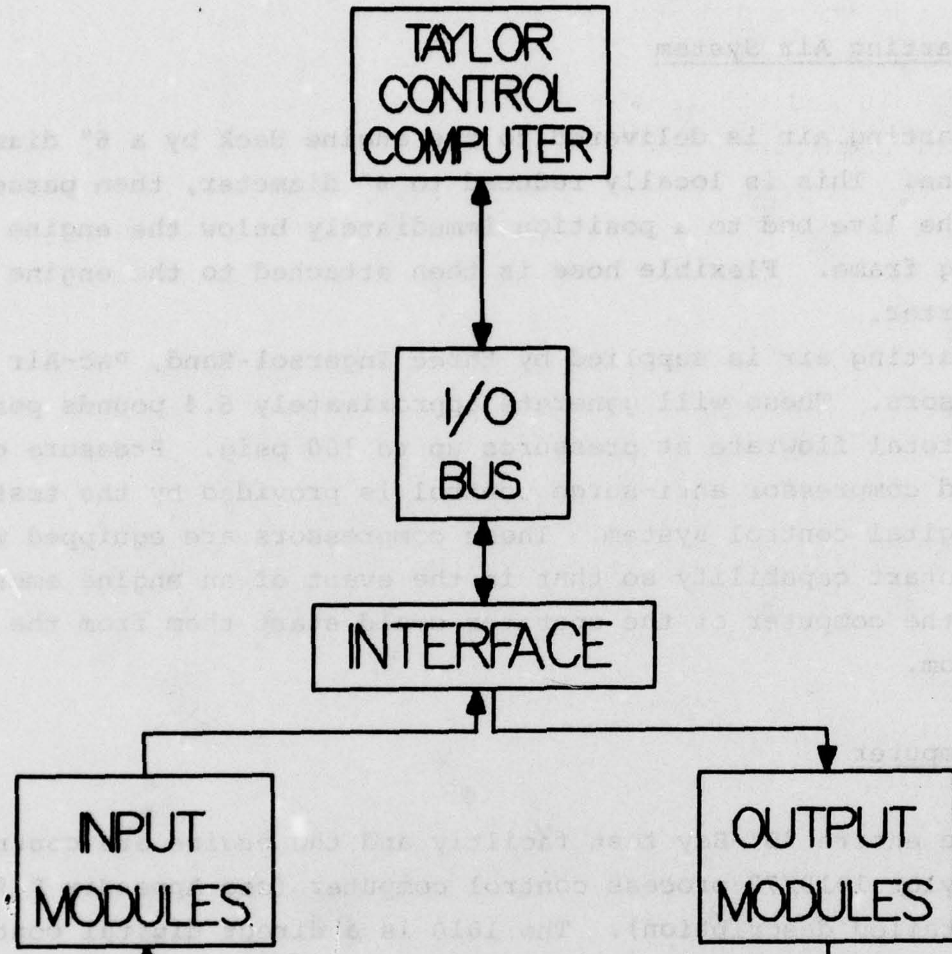


Figure 4 Computerized Process Control System

The action taken depends on the nature of the particular parameter that is out of limits. In addition to the control function, the Taylor 1010 and its peripheral equipment provide "D"-Bay's only means of acquiring, displaying and storing data.

The system in "D"-Bay is redundant with two identically configured process control computers connected together with a high speed memory link. A "bus switch" is used to allow the input and output lines to be rapidly switched to the backup computer in the event of a primary computer failure. All computer equipment, instrumentation, signal conditioning and control devices requiring electrical power are tied to the uninterruptable power system (UPS).

Modes of Operation

The computer control scheme breaks down the overall test function into five major "processes." These are: (1) Facility Start-up, (2) Engine Start-up, (3) Engine Run, (4) Engine Shut-down and (5) Facility Shut-down. Each of these processes contains its own consolidated data display, sequencing software, required interlocks, and emergency routines. Breaking the test function up this way allows for more convenient "bookkeeping" by the computer and a reduction in the number of programs which must remain core resident. In addition to the process break out, each of these individual processes may be placed in one of four operational modes. These modes are as follows:

Full Manual. This is a maintenance mode only. There is no computer control, no feedback, and no safety interlocks. The processor simply acts on command as an analog input/output device. The engine may not be operated in this mode. This is prevented by a programming "lock-out" of the main fuel valve anytime a process is in full manual.

Manual. This is also called "computer manual." It is very similar to the above condition except all safety interlocks are now functional and pre-programmed emergency action can take place. The engine may be operated in this and all subsequent modes.

Semi-Automatic. Upon operator command, the control system proceeds through a certain pre-set series of steps, then waits for instructions as to when to continue. This is the most common mode of operation.

Automatic. Following an initial command, all functions from initially opening inlet doors through a complete test program, to total facility shutdown are completed without further operator input.

The Engine Run process contains one additional piece of flexibility; i.e. that the throttle actuation may be either automatic or manual. Generally, all processes are left in semi-automatic to provide computer actuation of routine operations such as starting and stopping pumps, or moving control valves. However, once in Engine Run, the operators may place the throttle control in manual, regardless of the process mode. This allows test personnel to investigate engine characteristics without pre-programming a throttle actuation sequence. A similar situation occurs in the Engine Start process which allows a choice of either the operator or the computer to start the engine, once initialization checks are satisfied.

Throttle Control System

The only way in which the test cell control system interacts with the test engine is through the engine power lever. Power lever movement, or angle (commonly called PLA) when requested by the DDC, represents a demand input from the test cell control system. The throttle actuation system may be fully controlled by either the operator or the computer. However, should an emergency take place, the computer has the high priority on the system and can take control from the operator and return the engine to idle In these cases, the operator would have to clear the emergency in order to re-gain throttle authority.

The throttle actuation is accomplished electrically through a buffer/transmitter -- stepper motor drive. The buffer transmitter receives commands from the electronic logic package located in the control room. This then issues a number of steps at the desired rate to a stepper motor connected to the engine power lever. Feedback is accomplished through an optical encoder which is reading actual output shaft position. This eliminates feedback errors due to internal backlash.

Basic capabilities of the system include variable actuation rates from 0 to 300°/second; pre-set rates of 3°/second and 25°/second; limit and set point capability. The throttle may be manually moved at either of the pre-set rates to any position within limits via a joy stick actuator. In addition, the throttle may be moved at any of the adjustable rates by "dialing-in" the desired position via thumbwheel switches on the operators panel. Once this is completed, the control will move the throttle to that position at that rate by depressing a "set-point" button. Continuous LED digital readout is provided to the nearest 0.1 of a degree. Repeatability is maintained to $\pm$ 0.1 of a degree. The throttle control system is powered through the UPS system in case of electrical power failure.

One additional safeguard is provided. This is a function called: "chcp". This provides a direct input to the buffer transmitter and thus to the stepper motor. This combination will by-pass the electronic package and the computer system. It provides for a 25°/second motion, in a decreasing PLA direction, until a mechanical limit is reached. This immediately places the computer into manual and requires operator input to return to automatic.

Computer input to the throttle system is designed, in effect, to simulate the operator's input. All of the operator's controls and thumbwheel switches are capable of receiving binary coded decimal (BCD) input remotely. The computer tells the throttle system where the throttle position is to be, how fast to proceed, and when to execute the command. Actual accomplishment of the motion remains the responsibility of the throttle system itself.

Feedback of actual position is again accomplished through a BCD output from the throttle position indicator to the control system. It is important to note the fact that the throttle system logic and actuation are all self contained. The control computer does not have the capability of driving the buffer transmitter or correcting throttle errors. The control system simply makes a request of the throttle system, which then has to respond from its own internal resources. There is no mechanical link to the engine throttle shaft from the control room.

V. TEST CYCLES

Figures 5, 6, and 7, graphically represent the throttle transient profiles run during the test. Percent of design high pressure compressor rotational speed is plotted versus time. These cycles were programmed into the control computer, making use of the high pressure compressor speed, power lever angle relationship for this engine which was generated during the power calibration portion of this test. This is required because the automatic throttle controls power lever angle rather than compressor speed.

The cycle depicted in Figure 5 is designated the Flight cycle (also referred to as an "A" cycle) and is representative of the actual flight usage that the TF41's are seeing in the field. This cycle lasts 43 minutes and 29 seconds. It consists of a considerable number of engine accels and decels as well as a significant amount of time at maximum power. Figure 6, graphically depicts a Start cycle (also referred to as a "B" cycle) representative of flight line maintenance operation. Each "B" cycle includes 10 minutes and 30 seconds of engine operation and contains 3 engine starts and the remaining time at idle power. Figure 7, is a so-called Ground cycle (also referred to as a "C" cycle) which reproduces typical test cell and trim pad operation. This cycle lasts 2 hours 6 minutes and 15 seconds. It is composed of several accels from idle to relatively high power settings, followed by steady state operation at this condition, and then a decel to idle.

A complete TF41 AMT test consists of 15+ blocks of testing which is approximately 263 hours of operation. Each block is made up of 20 "A" cycles, 4 "B" cycles and 1 "C" cycle. A complete tabulation of the steps in each cycle may be found at the back of the test plan, Appendix E.

This combination of cycles is representative of the type of usage that a typical TF41 is subjected to in the field. A joint Allison and Air Force project compiled and analyzed data from many

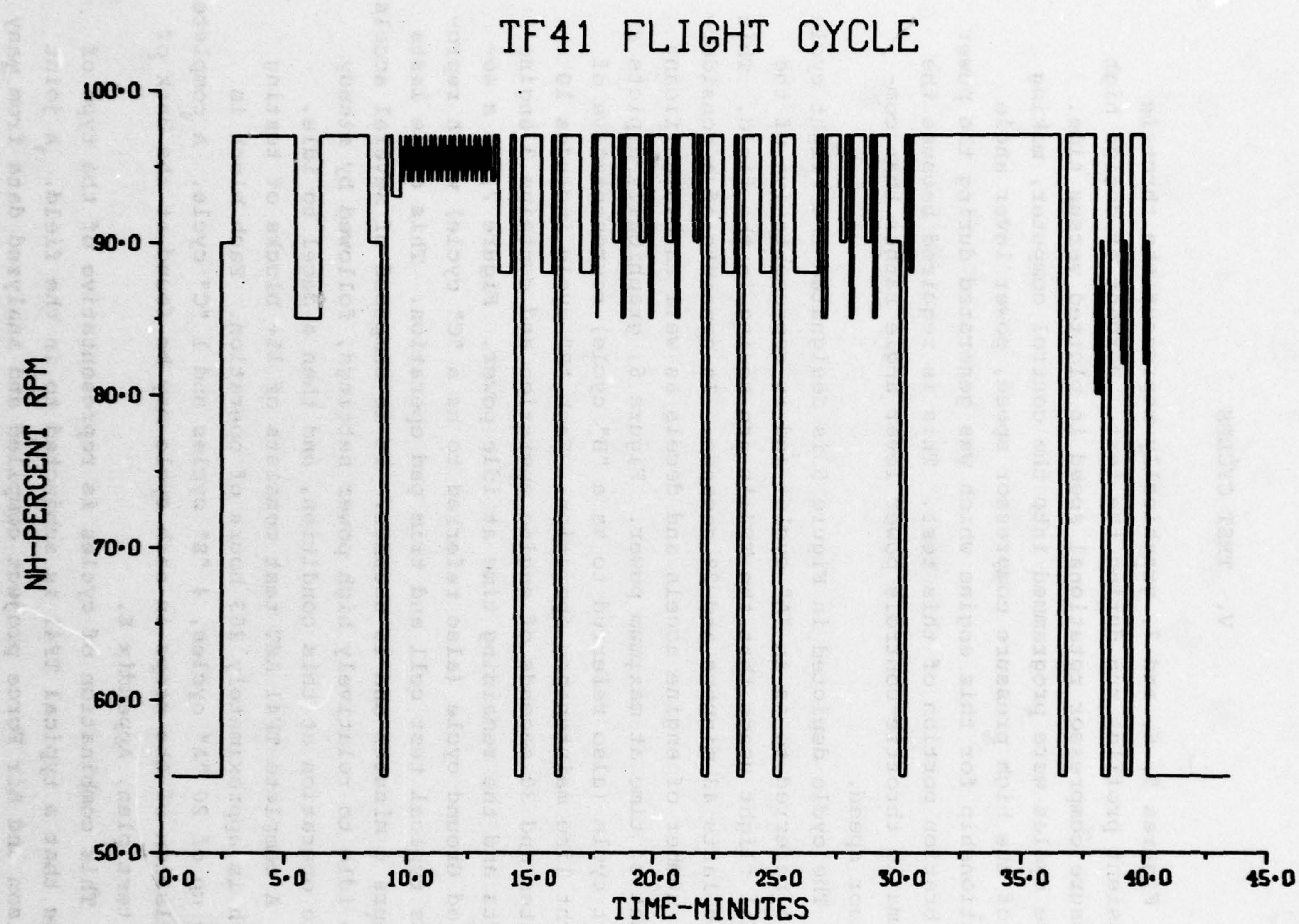


Figure 5 TF41 Flight Cycle

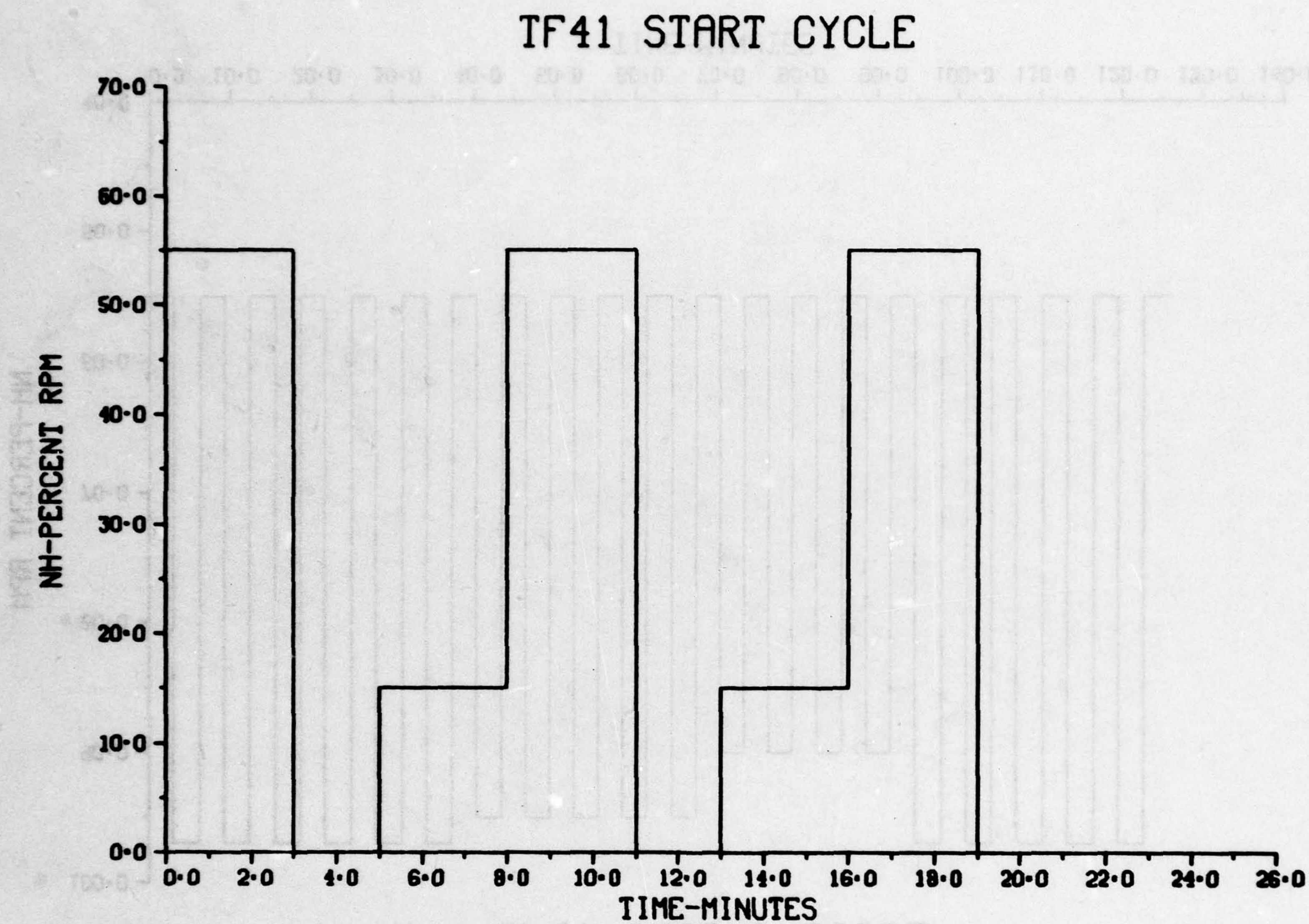


Figure 6 TF41 Start Cycle

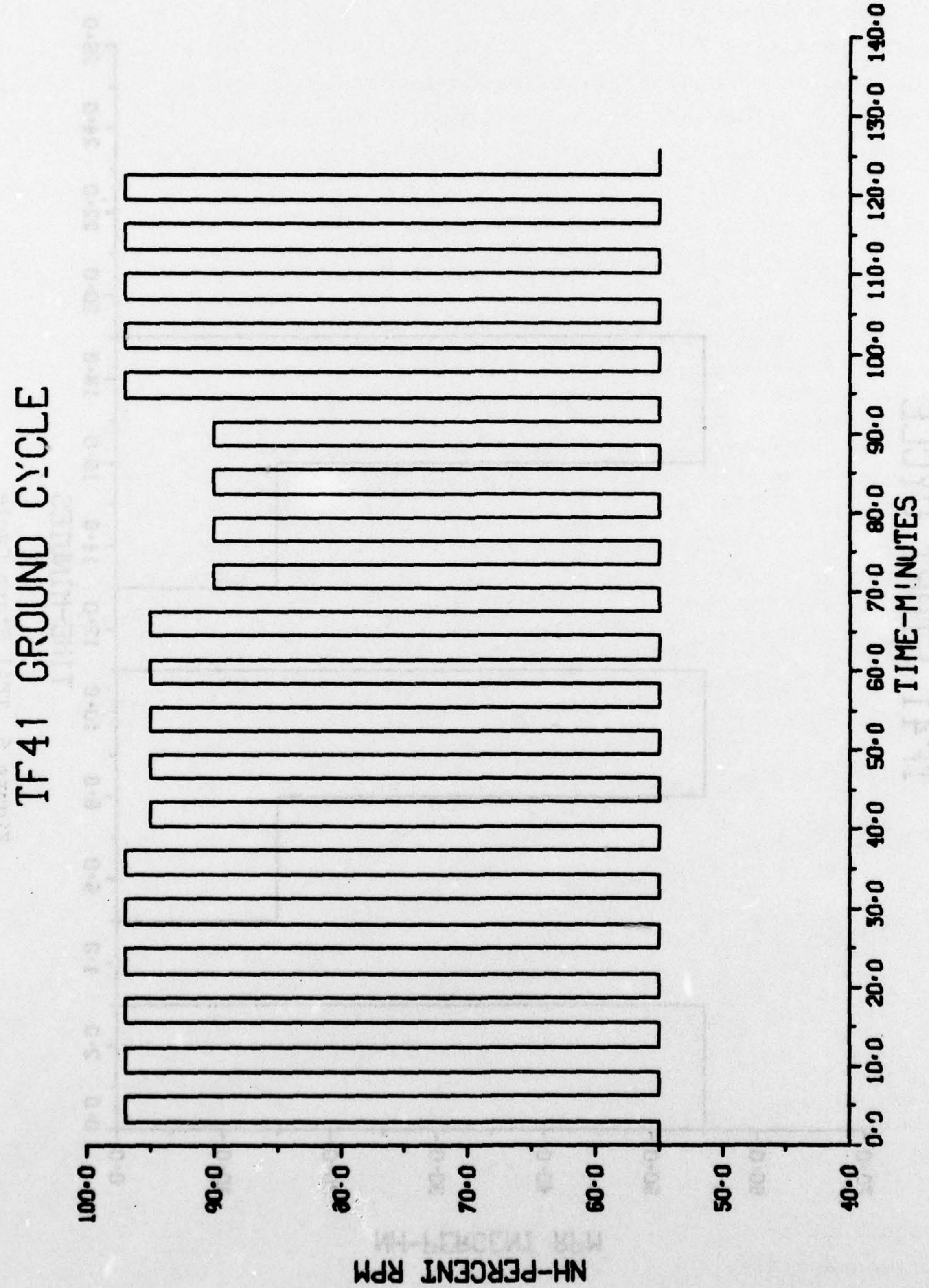


Figure 7 TF41 Ground Cycle

sources in order to derive these throttle profiles. Navy "Inflight Engine Condition Monitoring System" (IECMS) Data was used to provide records of engine histories during actual flight. An extensive program of pilot interviews was used to determine mission mix, estimates of throttle movement frequency, time at maximum power, effects of flight position (i.e., lead or wingman), mission profile definition (altitude, Mach number, time, weight, configuration), and the effects of pilot experience level. Also a flight test program was run at AFFTC, Edwards AFB CA using specially instrumented engines to define typical ranges of engine parameters during operational flight. Finally, engine data recorded during flight as part of the "Engine/Airframe Structural Integrity Program" (ENSIP/ASIP) was assessed.

All this data was analyzed and used to define the three real time cycles and the proper mix that would directly relate to real engine usage. The non-damaging portions of the cycles (i.e., low power operation and small throttle changes) were eliminated in order to compact the cycles. Thus, 1 AMT test hour is approximately equivalent to 1.9 flight hours.

VI. INSTRUMENTATION

All instrumentation located in the test facility, either engine or facility related, passes its signal through a signal conditioning room before being routed to the control computers. This provides a common interface location for all patching, calibrating, and adjusting activities. The signal conditioning room is provided with its own interactive terminal link to the digital control system.

On the engine test deck a signal distribution bus, or engine boom, is cantilevered from the cell wall to provide a hook up point for all engine data signals. A completely enclosed transducer cabinet also provides for local conversion of pressure signals to 0-5V output. This engine boom is permanently wired into the signal conditioning room and provided with various connectors for pressure, hydraulic, electrical, or thermocouple signals.

The following is a brief description of the current data channel capability:

Temperature Channels. Ninety-six (96), temperature (thermocouple) channels are provided. These channels are complete with all necessary signal conditioning and distributed into 40 Type K, 40 Type J, and 16 Type T couples. An ice point reference junction is provided for each channel in the signal conditioning room. Thermocouple jack panels on the engine boom are provided to facilitate installation.

Pressure Channels. The engine boom contains 68 pressure taps of two different types. Sixty of the taps are fitted with Tomco quick disconnect fittings and are limited to 500 psig (by the disconnect) and the other 8 are fitted with ordinary pipe fittings for high pressure hydraulic lines. A heated, enclosed cabinet is positioned on the engine deck for the mounting of transducers, thus limiting the distance the actual pressure signal must traverse.

Each channel of pressure must be equipped with a signal conditioner/ transducer to provide a 0-5 output, linear over the range of pressure to be measured. Cables to support these signals are provided from the engine deck to the signal conditioning room. A signal patch panel then provides a permanent path to the digital control system in the control room.

Undesignated Channels

There are 32, 0-5V input channels which are currently undesignated. These are provided with a Mil-Std, 5 pin connector at the engine boom. These connectors are then provided with signal cabling to the signal conditioning room and can be connected to the digital control system through a patch panel.

These channels are used to support signals from speeds, vibrations, flow-rates, positions, etc. The software which stipulates the parameters of the measured variable allows a change to be made in the designation via a keyboard entry from the control system, CRT terminal.

Engine Instrumentation

The following is a list of the primary engine related instrumentation which was available and operative during this test of TF41 S/N 142163. All the instrumentation was displayed as a digital output on a cathode ray tube (CRT) display which was updated continuously once per second. Data was recorded, as required, automatically using a line printer at the rate of once per minute.

1. Engine inlet total temperature (^{o}F) - the average of three iron-constantan thermocouples located in the air inlet bellmouth. The accuracy of this reading is $\pm$ $1^{o}F$. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

2. Engine inlet total pressure (PSIA) - the average of three total pressure probes located in the air inlet bellmouth. The accuracy of this reading is ± .01 PSIA.

3. Inlet static pressure (PSIA) - the average of three static pressure taps located in the air inlet bellmouth. The accuracy of this reading is ± .01 PSIA.

4. Low pressure compressor rotor speed (% Design RPM) - from an engine furnished tachometer on the L.P. gearbox. The accuracy of this reading is ± .2%. In addition to the CRT display it is also continuously recorded on an Offner oscillograph recorder.

5. High pressure compressor rotor speed (% Design RPM) - from a test equipment tachometer mounted on the H.P. gearbox. The accuracy of this reading is ± .1%. In addition to the CRT display it is continuously recorded on an Offner oscillograph recorder.

6. Turbine outlet temperature ($^{\circ}F$) - from nine engine furnished chromel-alumel thermocouples connected in parallel and electronically averaged. The accuracy of this reading is ± $4^{\circ}F$. In addition to the CRT display it is also recorded continuously on an Offner oscillograph recorder.

7. Fuel flow (LB_M/HR) - from a test cell furnished flow meter located in the fuel supply line to the engine. The range of this meter is 0-11,000 LB_M/HR. The accuracy of this reading is ± .5%. In addition to the CRT display it is continuously recorded on an Offner oscillograph recorder in the control room.

8. Fuel inlet temperature ($^{\circ}F$) - from a closed-tip type iron-constantan thermocouple located in the test stand fuel line near the flow meter. The accuracy of this measurement is ± $1^{\circ}F$.

9. High pressure compressor discharge static pressure (PSIG) - from a static pressure tap located on the number nine strut in the

diffuser. The measurement is from an engine furnished fitting on the fuel control sense line. The accuracy of this measurement is ± .05 PSI.

10. High pressure compressor discharge temperature (^{o}F) - from two engine furnished chromel-alumel thermocouples located in numbers three and nine fuel nozzles and averaged. The accuracy of this reading is ± 1^{o}F.

11. Fuel manifold pressure (PSIG) - from a pressure tap on the fuel manifold on the left side of the engine. The accuracy of this measurement is ± 1%.

12. Low pressure turbine discharge total pressure (PSIG) - from nine engine furnished total pressure probes spaced circumferentially in the turbine exhaust. The measurement is picked up from the P5.1 pressure manifold tap. The accuracy of this measurement is ± .1 PSI.

13. Main oil pressure drop (ΔP) (PSID) - from high pressure fitting on oil filter and low pressure fitting on oil cooler inlet flange. This measures engine main oil pressure minus internal gearbox oil pressure. The accuracy of this measurement is ± .5 PSID.

14. Engine main oil pressure (PSIG) - from a high pressure fitting on the oil filter. The accuracy of the measurement is ± .5 PSI.

15. Low pressure cooling air discharge temperature (^{o}F) - taken at the jack on the L.P. cooling air duct fitting using an iron-constantan thermocouple. The accuracy of this measurement is ± 1^{o}F.

16. Engine vibrations (mils)

- Front compressor (vertical) - mounted on the front flange on top of the engine.

- Rear compressor (vertical) - mounted on the fuel manifold boss on top of the engine.

- Turbine (near vertical) - mounted on the low pressure turbine oil tube boss on the bottom of the engine.

17. IGV position (degrees) - an angle probe mounted on the engine airflow regulator and measures regulator travel in terms of HP inlet guide vane angle.

18. Power lever position (degrees) - measures the total cambox lever travel. The accuracy of this measurement is $\pm 1^{o}$. In addition to the CRT this parameter is a digital display on the auto-throttle control panel.

19. Engine oil inlet temperature (^{o}F) - from a closed tip iron-constantan thermocouple located in the tube to the L.P. turbine bearing. The accuracy of this reading is $\pm 1^{o}F$.

20. Engine thrust (LB_F) - from load cell deflection. The range of the load cell is -60 to +60 KLBS. The accuracy of this reading is $\pm$ 100 LBS.

21. Fuel inlet pressure (PSIG) - from a measurement taken near the L.P. fuel pump inlet. The accuracy of this measurement is $\pm$ 1 PSIG.

22. Oil tank temperature (^{o}F) - from a closed tip iron-constantan thermocouple mounted in place of the oil tank drain plug which senses engine oil outlet temperature as measured at the oil tank. The accuracy of the measurement is $\pm 1^{o}F$.

23. Junction box temperature (^{o}F) - from an iron-constantan thermocouple installed on the small mounting lug for the ballast resistor in the T5.1 thermocouple junction box. The accuracy of this measurement is $\pm 1^{o}F$.

24. Pilot fuel manifold pressure (PSIG) - from a pressure tap on the pilot manifold near the main manifold pressure tap. The accuracy of this reading is ± 25 PSIG.

25. Temperature limiter amplifier current (Milliamps) - measures current to the main fuel control limiting solenoid. Taken from pins 12 and 13 of amplifier test connector on the temperature limiter amplifier. The accuracy of this measurement is ± .5 milliamps. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

26. Ambient pressure (in HG) - from a barometer located on the outside wall of the test cell.

27. Wet bulb temperature (^{o}F) - measurement made periodically in the test cell using a sling psychrometer.

28. Dry bulb temperature (^{o}F) - measurement made periodically in the test cell using a sling psychrometer.

29. 11th stage bleed total pressure (PSIA) - from a pressure probe located in the 11th stage compressor customer bleed port. The accuracy of this reading is ± .1 PSIA.

30. 11th stage bleed static pressure (PSIA) - from a static tap on the probe located in the 11th stage compressor bleed port. The accuracy of this reading is ± .1 PSIA.

VII. DISCUSSION OF THE TEST

SUMMARY

An accelerated mission test of a TF41 (S/N 142163) with "Block 76" hardware was conducted at the Air Force Aero Propulsion Laboratory's sea level engine test facility, "D"-Bay. A complete accelerated mission test normally consists of 263 endurance hours, made up of 305 "A" cycles, 60 "B" cycles, and 15 "C" cycles. Only 106 endurance hours (144 total operating hours) were completed before a second stage high pressure turbine failure ended the test. 118 "A" cycles, 31 "B" cycles, and 7+ "C" cycles were completed.

ENGINE RELATED INCIDENTS

In general, up to the turbine failure, the TF41 engine tested in this program operated extremely well, with a minimum number of mechanical problems. The more important engine related incidents that occurred during the test are summarized below:

- Oscillation in NH (± 2%) - occurred during initial runs and reoccurred periodically throughout the early part of the test. Stable operation returned after bleeding the fuel system. When the instability kept reoccurring, a procedural change was instituted which called for checking the auto-throttle limits with fuel at the engine. The problem did not return after this.

- Crack in L.P. Turbine Bearing Support Fairing - Two cracks of approximately 2 inches each in length were discovered on the struts at approximately the 2 o'clock and 7 o'clock positions on the fairing during the 100 hour phase inspection. The cracks were repaired by stop drilling and welding.

- Low Idle Speed - After approximately 53 AMT hours (86 total engine operating hours) the idle RPM (high pressure rotor speed) had fallen below T.O. limits to 52.5%. The idle speed stop was adjusted 1/4 turn clockwise and the idle speed increased to 55.2%

- Misset NH Governor - During the pre-test functional checks it was noticed that the NH governor was set low. No adjustment was made at this time. However, during the early testing it became apparent that the engine was not performing properly and control interference was suspected. After 27 AMT test hours (55 total engine operating hours) the governor was reset by adjusting the governor maximum stop and shortening the main fuel control lever. Engine operation was normal after this adjustment.

- Turbine Failure - After approximately 106 AMT hours (144 total engine operating hours), 19 minutes into the 8th "C" cycle at intermediate power a ball of flame was observed out the back of the tailpipe. Immediately, control computer alarm limits on turbine vibrations (5.0 mils) and exhaust gas temperature (1084^{o}F) were exceeded and the engine started winding down. The engine was returned to idle power and then shutdown. Visual inspection showed considerable damage to the last turbine stages and the engine was removed and shipped to Allison.

TEST PROCEDURES

Throughout this entire test program, the engine was operated in accordance with the procedures and limits (except mass flow limiter) contained in Air Force Tech Order, T.O. 2J-TF41-6 and Allison Publication Nr 1F2, TF41-A-1 Engine Operation and Service. Prior to each day's running, a pre-test checklist, including a visual inspection of the engine and test cell were completed. Oil level was checked several times during the day and rotor coastdowns were recorded upon the last shutdown of each test period.

A functional check of the engine's limiters, governors, and schedules was performed before the endurance portion of the test and a similar check was planned after every 100 AMT hours of testing. A pre-test steady-state power calibration, between 50% power and maximum power was also carried out. An additional series of steady-state points were run to define the high pressure compressor rotor speed/power lever angle relationship needed to input the test cycles into the automatic throttle controller. Additional

calibrations were scheduled in 100 AMT hour intervals and after completion of the test.

Engine maintenance and inspections were planned at 50 hour intervals according to Allison publication 1F2. Borescoping of the engine was to be performed after every 100 AMT hours. Oil samples were taken after approximately 25 hours of engine operating time.

During the test operation, all facility and engine instrumentation was monitored by the test operator and the test cell observer using CRT displays. Data was only recorded using the line printer during the six minute constant power level operation at intermediate power (referred to as the "Intermediate Power Flat") which occurs near the end of every "A" cycle and was processed by a data reduction computer program (using methods outlined in Appendix A) after each day's run. However, thrust, fuel flow, low pressure and high pressure rotor speeds, exhaust gas temperature, ambient temperature, and temperature limiter amplifier current were recorded continuously on an oscillograph recorder.

Normally, the endurance portion of an AMT test is run in a series of blocks, each block consisting of 20 "A" cycles, followed by 4 "B" cycles, followed by 1 "C" cycle. However, due to the difficulty in changing cycles in the control computer this sequencing was not followed.

The usual AMT test procedure is to set the 11th stage compressor customer bleed at 1.5 lbs/sec and leave it constant throughout the endurance portion of the program. However, since "D"-Bay cannot supply heated inlet air in this test, customer bleed was used to keep the turbine stator inlet temperature at as high a level as possible during low engine inlet temperature operation. Bleed flow was varied between 1.5 lbm/sec and 4.5 lbm/sec depending on the temperature of the day by changing an oriface plate at the bleed discharge port. Six different bleed settings were possible. A special algorithm was built into the control computer so that a calculated turbine inlet temperature could be displayed and monitored "on line". Based on this reading, the 11th stage bleed was changed to maintain operation at acceptable levels of turbine inlet temperature.

Allison felt that in order to obtain meaningful results from this AMT test, turbine inlet temperature at intermediate power should be greater than 2100^{o}F. The combination of bleed and some engine control adjustments made it possible to run above this lower limit with ambient temperatures as low as 30^{o}F. On days colder than this, "B" cycles were run since the engine only reaches idle power and there is little impact of ambient temperature.

TRIM

TF41 S/N 142163 was trimmed at Indianapolis in one of Allison's production facilities before being sent to AFAPL for AMT testing. The objective of a production trim is to meet design thrust at the lowest possible turbine inlet temperature for improved life. However, one of the basic ground rules of an AMT test is to run the engine at maximum turbine inlet temperature at intermediate power. TF41 S/N 142163 was a relatively good engine and made design performance at a relatively low turbine inlet temperature.

TF41 temperature trim is adjusted by changing a ballast resistor in the control which changes the relationship between the actual measured exhaust gas temperature and the temperature input to the fuel control. In effect, changing the resistor allows operation to a different exhaust gas temperature which in turn results in a change in turbine inlet temperature.

The procedure for picking the new trim resistance is as follows: A plot of corrected turbine inlet temperature is made using the pretest performance calibration data (Figure 8). This plot shows that an additional 9.6^{o}F of exhaust gas temperature is required to allow operation at the 2165^{o}F turbine temperature limit. Using the relationship:

$$(T5.1_{actual} - T5.1_{indicated}) = \left(\frac{RH}{RB}\right) (T5.1_{indicated} - TJB) \qquad (1)$$

where,

$T5.1_{actual}$ is the actual exhaust gas temperature

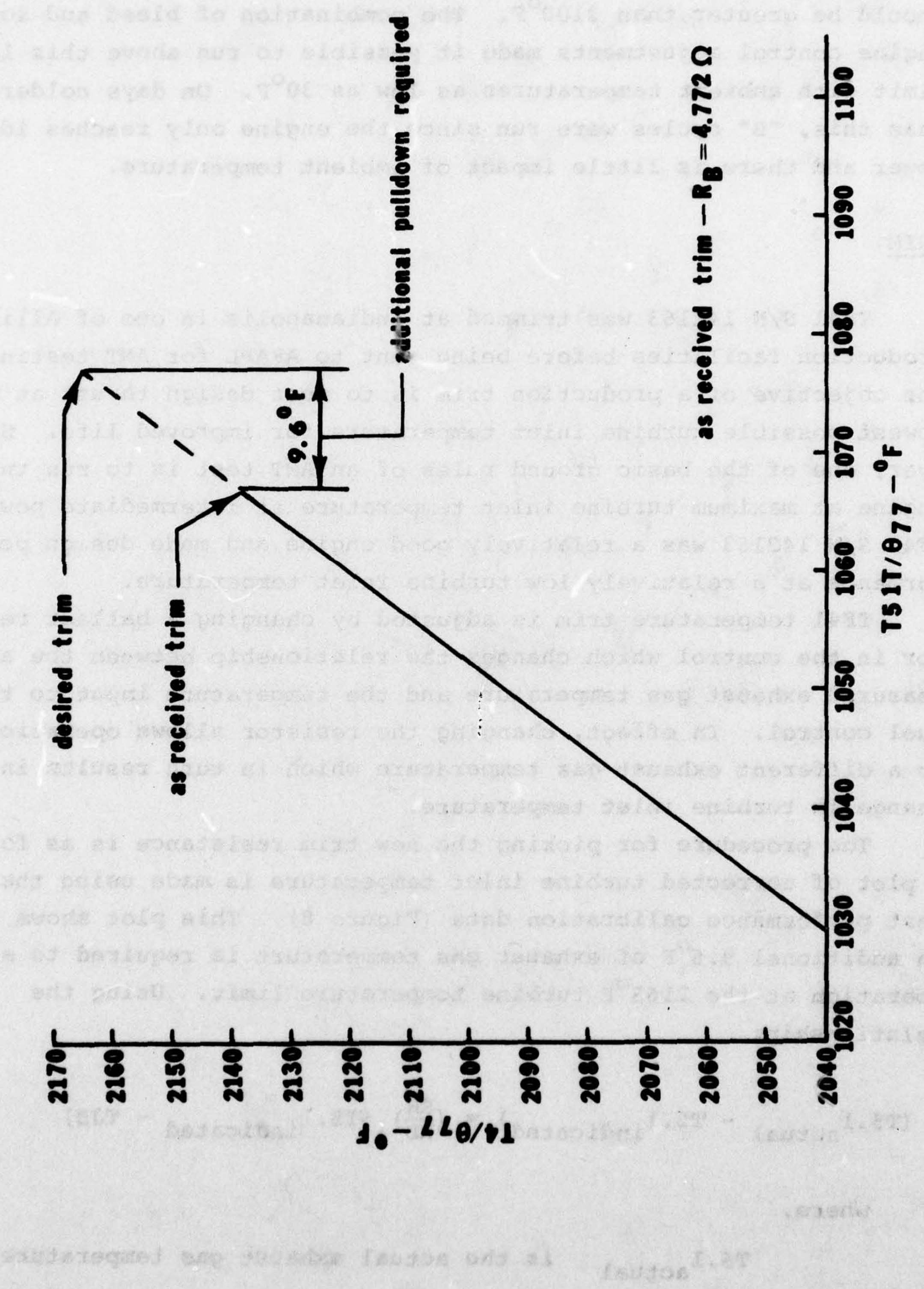


Figure 8 T51 Retrim

$T5.1_{indicated}$	is the indicated exhaust gas temperature
TJB	is the junction box temperature
RH	is the harness resistance (.6677)
RB	is the trim resistance

and the original trim resistance (4.772 Ω) allows calculation of the original trim pulldown (difference between $T5.1_{actual}$ and $T5.1_{indicated}$). The additional pulldown from Figure 8 is added to this number and equation 1 is again solved for the new trim resistance. A comparison of the "as received" and retrimmed parameters is contained in Table 2.

With normal TF41 trim, when the engine inlet temperature is less than about 70°F, the engine is governed at intermediate power by the "mass flow limiter" which in effect limits the fan corrected speed to some predetermined value. This causes the lapse in turbine inlet temperature on cold days which adversely impacts the ability to run TF41 AMT tests in the cold weather in "D"-Bay. The specified mass flow limit on the TF41 is set by the inlet size of the A7. However, in the test cell, this limit is not applicable and the mass flow limiter can be adjusted to higher levels without damaging the engine. This adjustment was made and the "as received" and retrimmed parameters for operation on the mass flow limiter are contained in Table 2.

INLET TEMPERATURE/TURBINE STATOR INLET TEMPERATURE (T4) TIME SUMMARY

Previous TF41 AMT tests were run with controlled engine inlet temperature. Forty-one percent of the test was run at 70°F ± 5°F, 38% was run at 90°F ± 5°F, 9% was run at 110°F ± 5°F and the remaining 12% (the "C" cycles) were run at various inlet temperatures. It was not possible to match this distribution since "D"-Bay does not have any means for controlling the inlet air temperatures. The ambient temperature distribution that was run during this test is presented in Figure 9.

TABLE 2 RETRIMMED PERFORMANCE

TEMPERATURE TRIM

PARAMETER	AS RECEIVED	RETRIMMED
FG/δ	14393 LB	14700 LB
$T4/\theta_{77}$	$2138^{o}F$	$2165^{o}F$
RB	4.772	4.469

MASS FLOW TRIM

PARAMETER	AS RECEIVED	RETRIMMED
$NL\sqrt{\theta_{59}}$	8625 RPM	9010 RPM
$W_A\sqrt{\theta}/\delta$	255 LBM/SEC	267 LBM/SEC
FG/δ	14,400 LB_F	16,300 LB_F

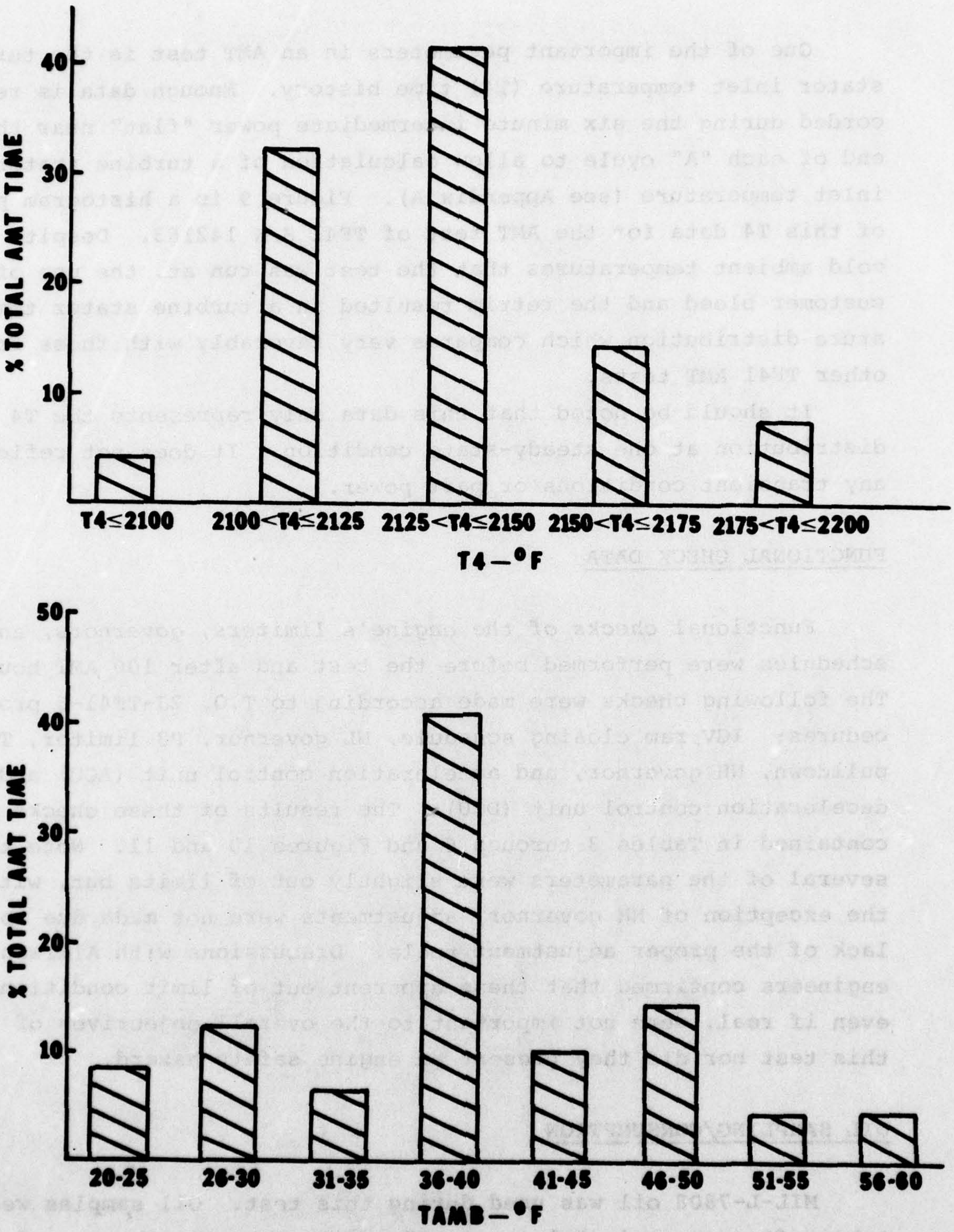


Figure 9 Ambient Temperature and Calculated Turbine Stator Inlet Temperature Time History

One of the important parameters in an AMT test is the turbine stator inlet temperature (T4) time history. Enough data is recorded during the six minute intermediate power "flat" near the end of each "A" cycle to allow calculation of a turbine stator inlet temperature (see Appendix A). Figure 9 is a histogram plot of this T4 data for the AMT test of TF41 S/N 142163. Despite the cold ambient temperatures that the test was run at, the use of the customer bleed and the retrim resulted in a turbine stator temperature distribution which compares very favorably with those from other TF41 AMT tests.

It should be noted that this data only represents the T4 distribution at one steady-state condition. It does not reflect any transient conditions or part power.

FUNCTIONAL CHECK DATA

Functional checks of the engine's limiters, governors, and schedules were performed before the test and after 100 AMT hours. The following checks were made according to T.O. 2J-TF41-6 procedures: IGV ram closing schedule, NL governor, P3 limiter, T5.1 pulldown, NH governor, and acceleration control unit (ACU) and deceleration control unit (DCU). The results of these checks are contained in Tables 3 through 6 and Figures 10 and 11. Note that several of the parameters were slightly out of limits but, with the exception of NH governor, adjustments were not made due to a lack of the proper adjustment tools. Discussions with Allison engineers confirmed that these apparent out of limit conditions, even if real, were not important to the overall objectives of this test nor did they present an engine safety hazard.

OIL SAMPLING/CONSUMPTION

MIL-L-7808 oil was used during this test. Oil samples were taken after approximately every 25 engine operating hours and sent to the Air Force Aero Propulsion Laboratory's Fuels and Lubrications

TABLE 3 NL GOVERNOR CHECK

	T.O. Limit	0 Hours	100 Hours
NL (RPM)	7947-8002	7975	7912*

*Low but no adjustment made

TABLE 4 NH GOVERNOR CHECK

	T.O. Limit	0 Hours	100 Hours
NH (RPM)	13000-13070	12785/13069**	13069

**Retrimmed value

TABLE 5 P3 LIMITER CHECK

	T.O. Limit	0 Hours	100 Hours
P3 (PSIG)	145-155	157.4*	159.2*

*High but no adjustment made

TABLE 6 T5.1 PULLDOWN CHECK

	T.O. Limit	0 Hours	100 Hours
T5.1(^{o}F)	884.5-888.5	888.5	888.5

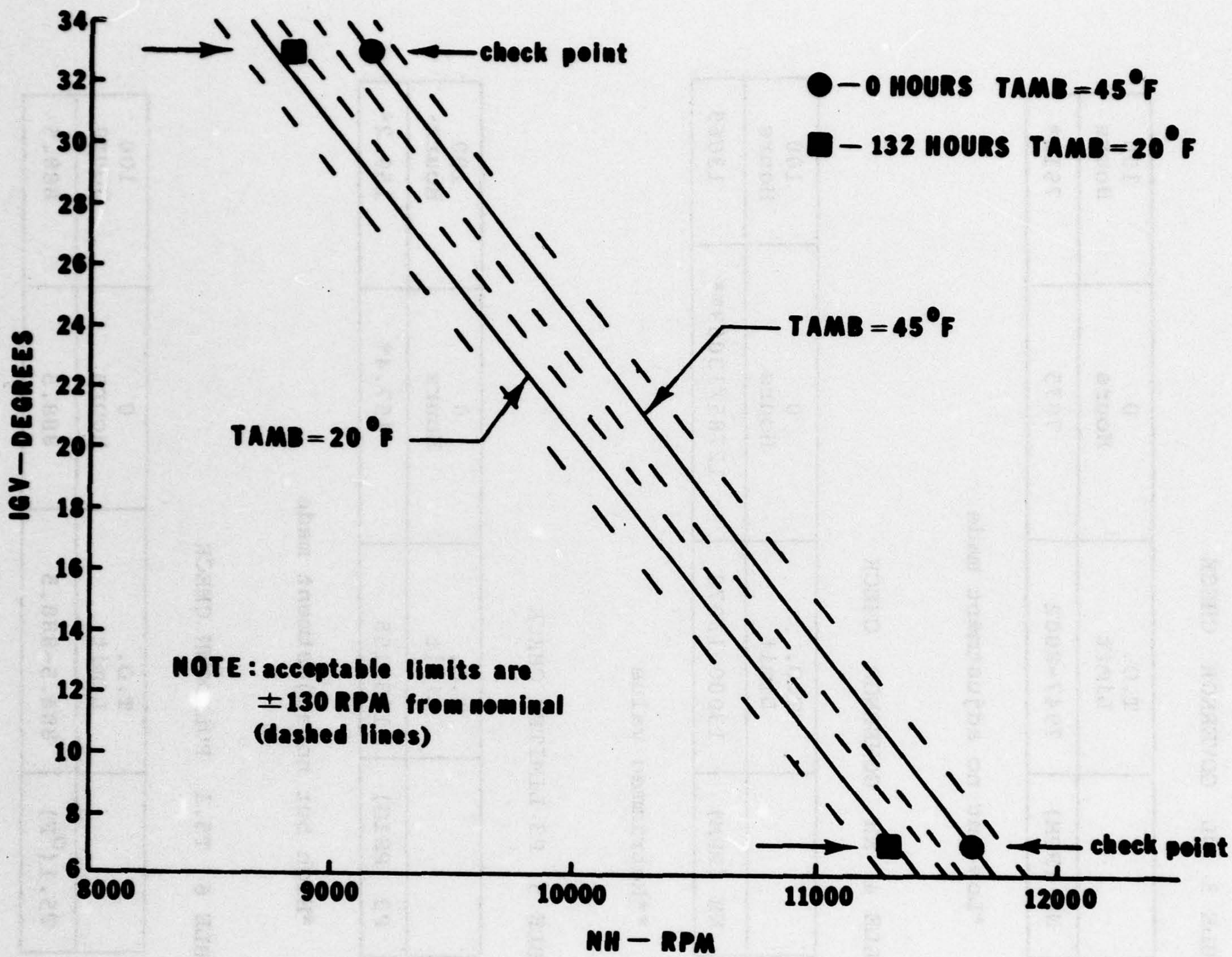


Figure 10 H.P. IGV Scheduling

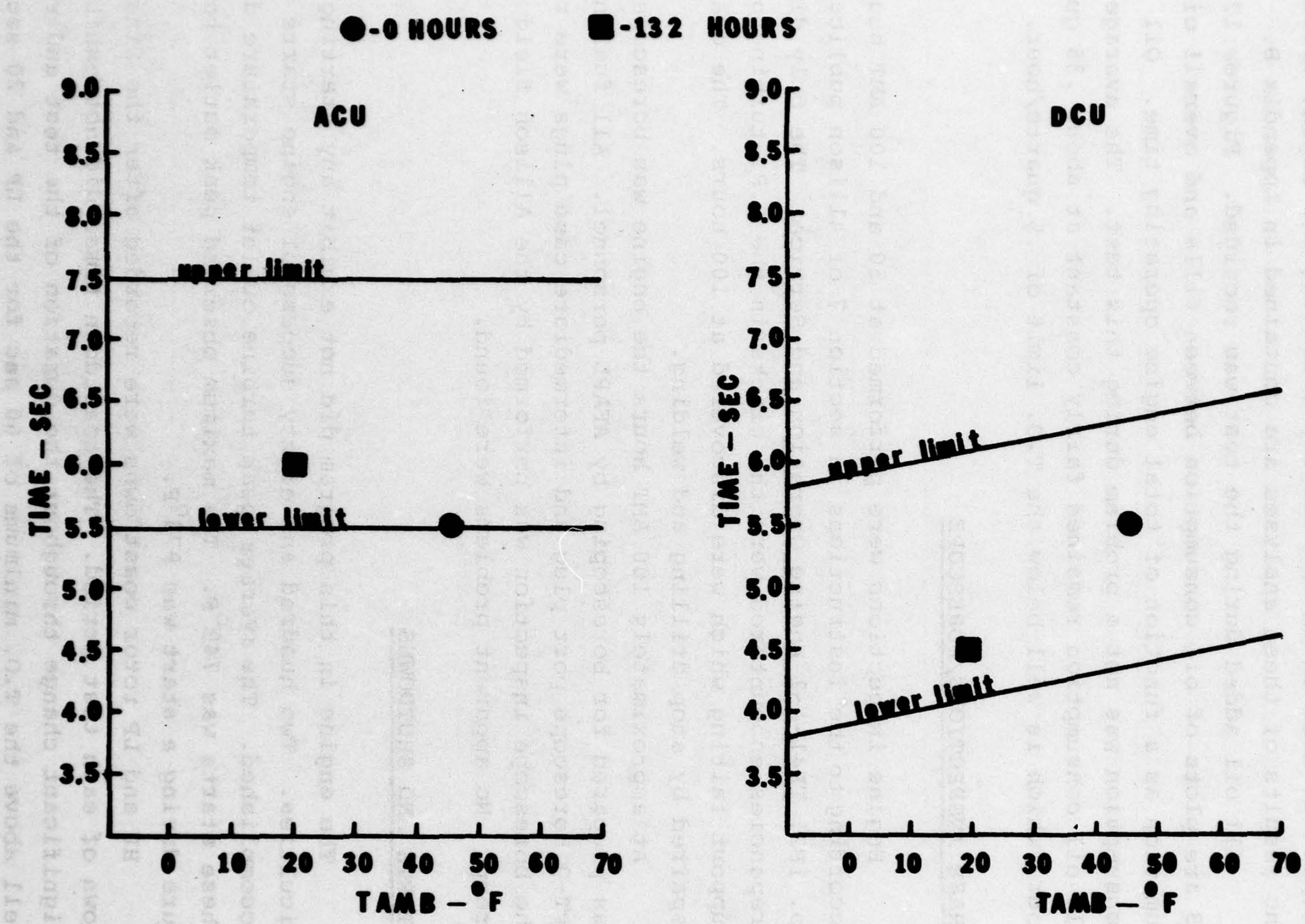


Figure 11 ACU/DCU Time Checks

Division for spectrometric (SOAP) and ferrograph analyses. An oil sample was also taken immediately following the engine failure. The results of these analyses are contained in Appendix B.

All oil added during the test was recorded. Figures 12 and 13 are plots of oil consumption between fills and overall oil consumption as a function of total engine operating time. Oil consumption was not a problem during this test. The average overall oil consumption remained fairly constant at about .35 quarts/hour, which is well below the T.O. limit of .5 quarts/hour.

PHASE INSPECTIONS/BORESCOPE

Engine inspections were performed at 50 and 100 AMT hours according to the instructions in section 7 of Allison publication No. 1F2, TF41-A-1 Engine Operation and Service. The only discrepancies encountered were the cracks in the L.P. turbine bearing support fairing which were discovered at 100 hours. The cracks were repaired by stop drilling and welding.

At approximately 100 AMT hours the engine was borescoped. It was prepared for borescoping by AFAPL personnel. All fuel nozzles, HPT-2 borescope port plug and intermediate case plugs were removed. The borescope inspection was performed by the Allison field service group. No apparent problems were found.

STARTS AND SHUTDOWNS

The engine in this program did not exhibit any starting difficulties. Two hundred and eighty successful engine starts were accomplished. The average peak turbine outlet temperature during these starts was 749°F. The maximum observed peak outlet temperature during a start was 974°F.

HP and LP rotor coastdowns were recorded after the final shutdown of each test period. The coastdown times did not exhibit any significant change throughout the duration of the test and remained well above the T.O. minimums of 60 sec for the LP and 20 sec for the HP.

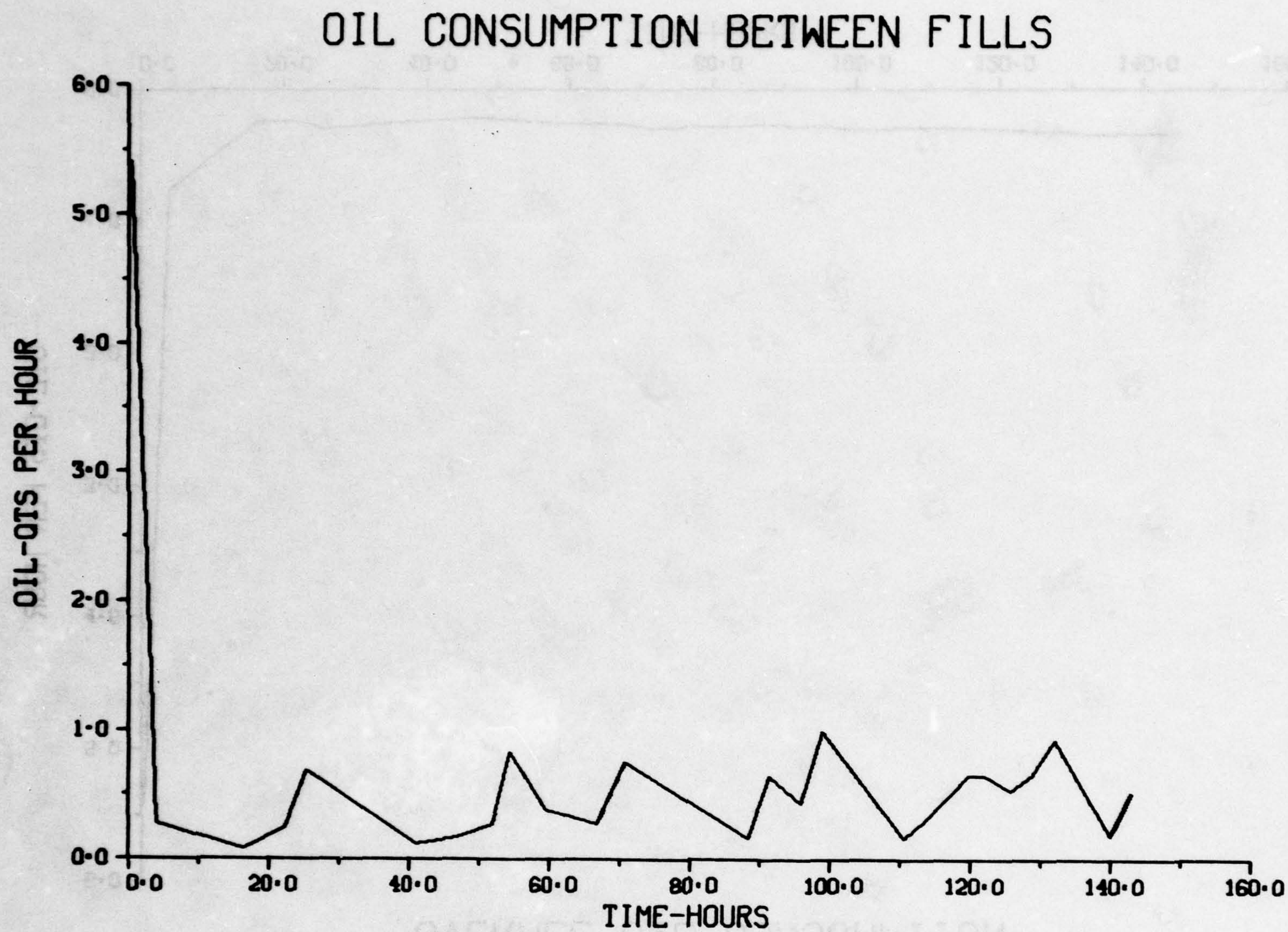


Figure 12 Oil Consumption between Fills

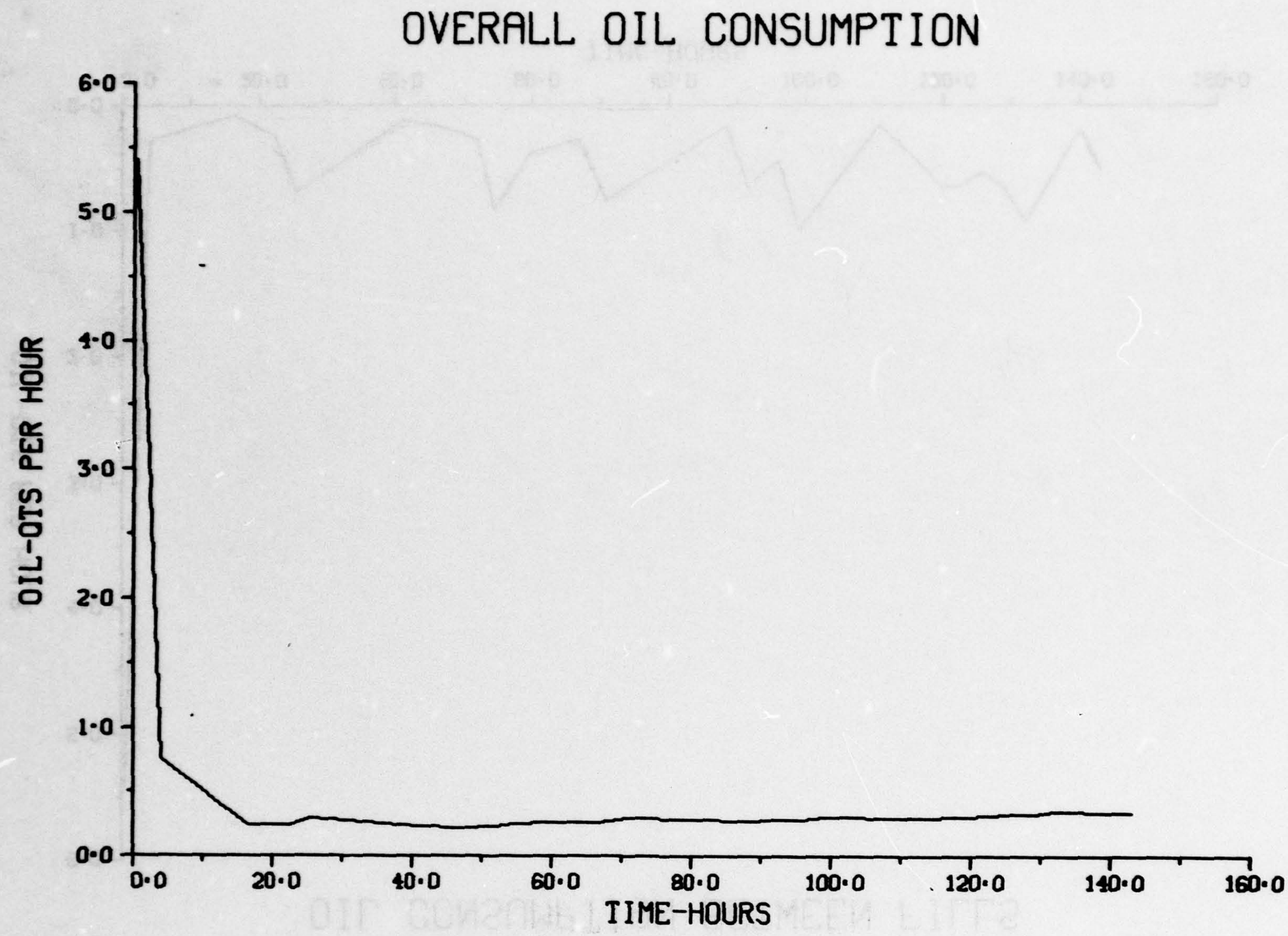


Figure 13 Overall Oil Consumption

Initial coastdowns	-	LP	-	140 sec
		HP	-	87 sec
Final coastdowns	-	LP	-	132 sec
		HP	-	83 sec

VIBRATIONS

Turbine, compressor, and mid-frame vibrations were recorded during the power calibrations at 0 and 100 AMT hours and are plotted as a function of high pressure compressor RPM in Figure 14. Throughout the test, the vibrations remained well below the T.O. limit of 5.0 mils, until the turbine failure. In addition, they did not show any significant change with engine operating time.

"A" CYCLE PERFORMANCE DATA

A steady-state data point was recorded at intermediate power during the six minute "flat" near the end of each "A" cycle. The raw data was processed through a data reduction computer program based on the equations in Appendix A. Plots of corrected high pressure rotor speed (NHC1), corrected low pressure rotor speed (NLC1), corrected fuel flow (WFC59), corrected turbine discharge pressure (P51C), corrected airflow (W2C1), turbine inlet temperature corrected to 77°F (T4C77), and trimmed turbine exhaust gas temperature corrected to 77°F (T51TC7) and corrected to 59°F (T51TC5) versus thrust corrected to 59°F (FGC59) or 77°F (FGC77) are presented in Figures 15 through 22.

Even though all the data points plotted are at intermediate power, there is a variation in corrected thrust due to the varying engine inlet temperatures, varying customer bleed flow and also engine deterioration. The relatively large amount of scatter in the data is the result of several factors. The control computer, which acquires the instrumentation signal, processes it, displays

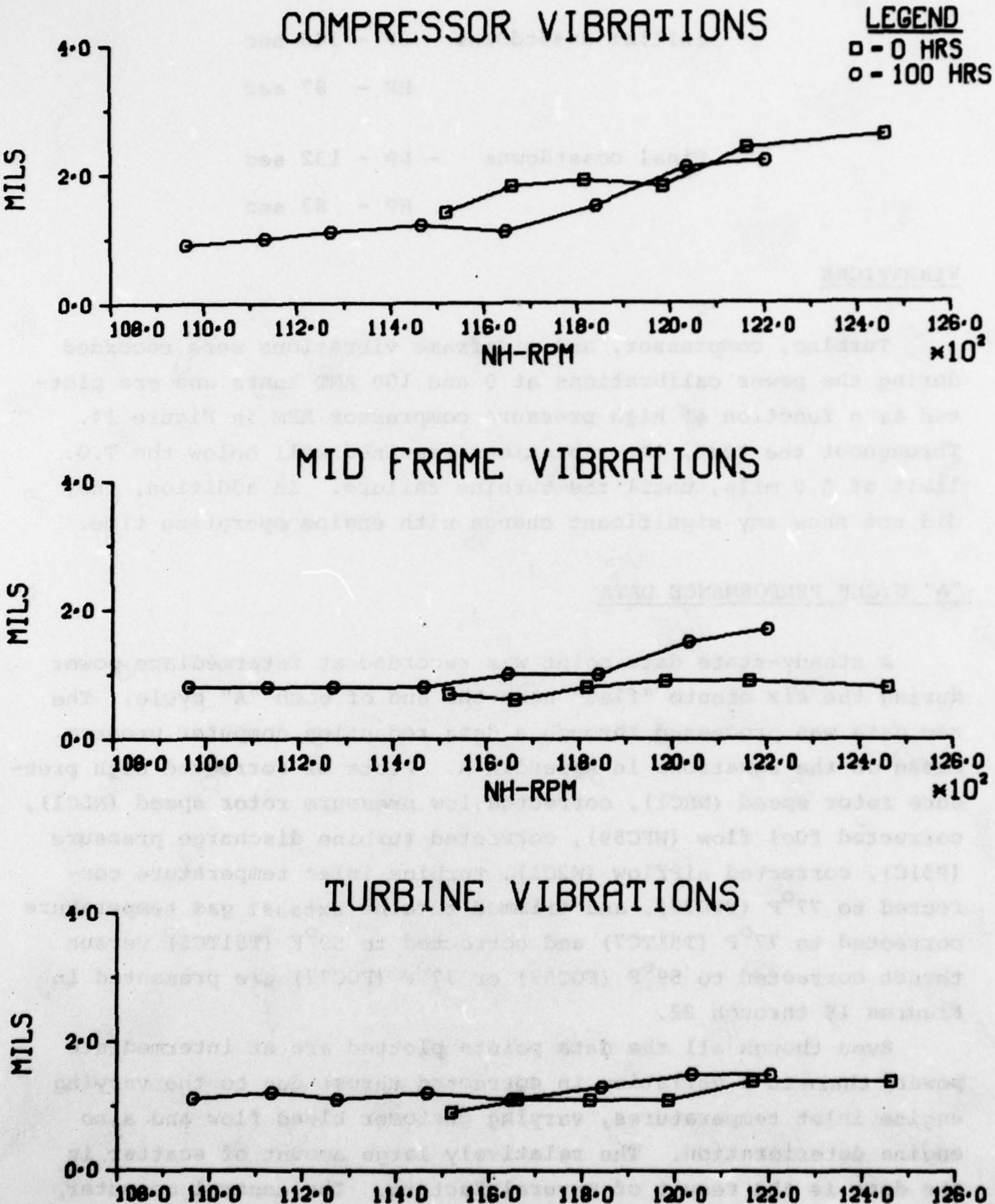


Figure 14 Engine Vibration History

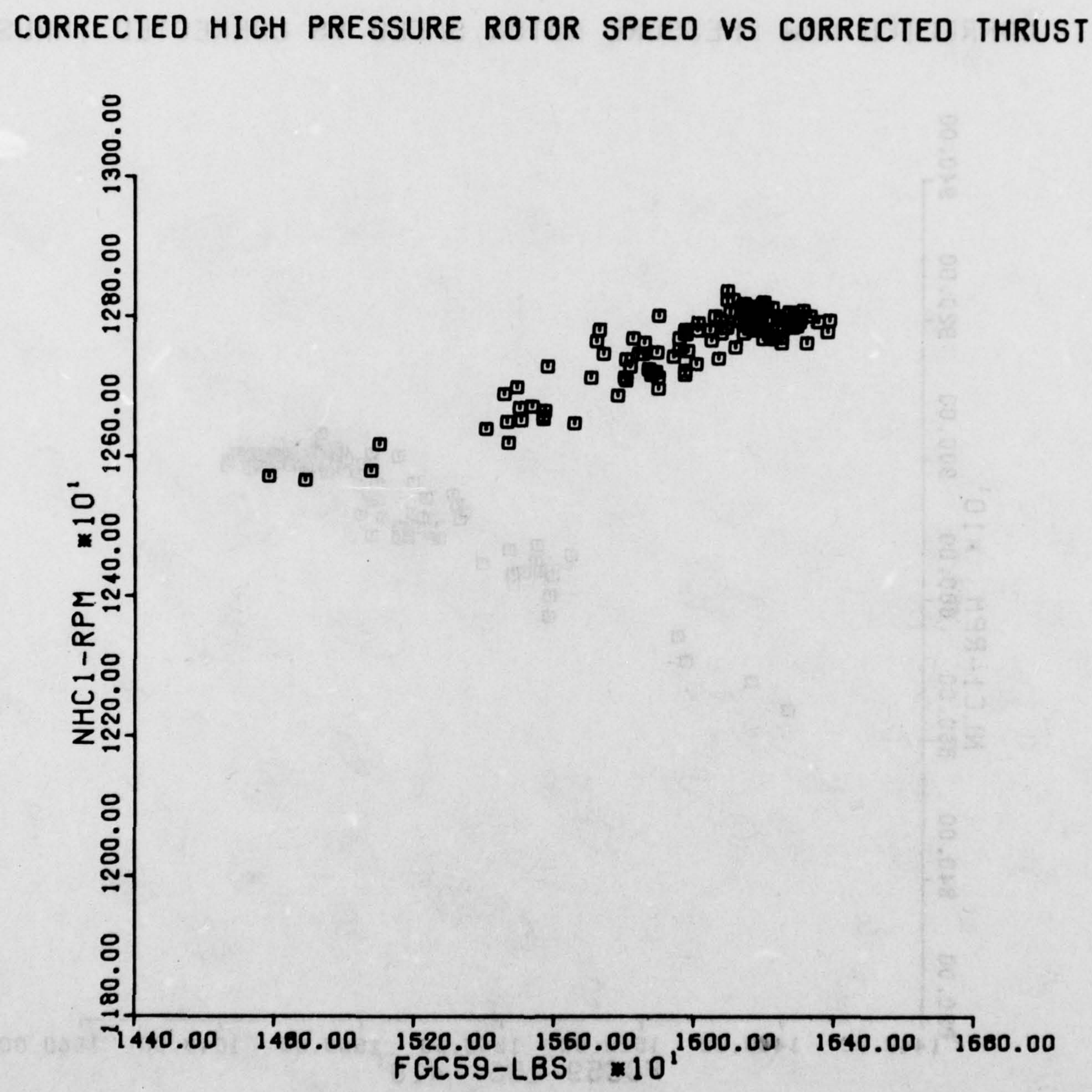


Figure 15 Corrected High Pressure Rotor Speed versus Corrected Thrust

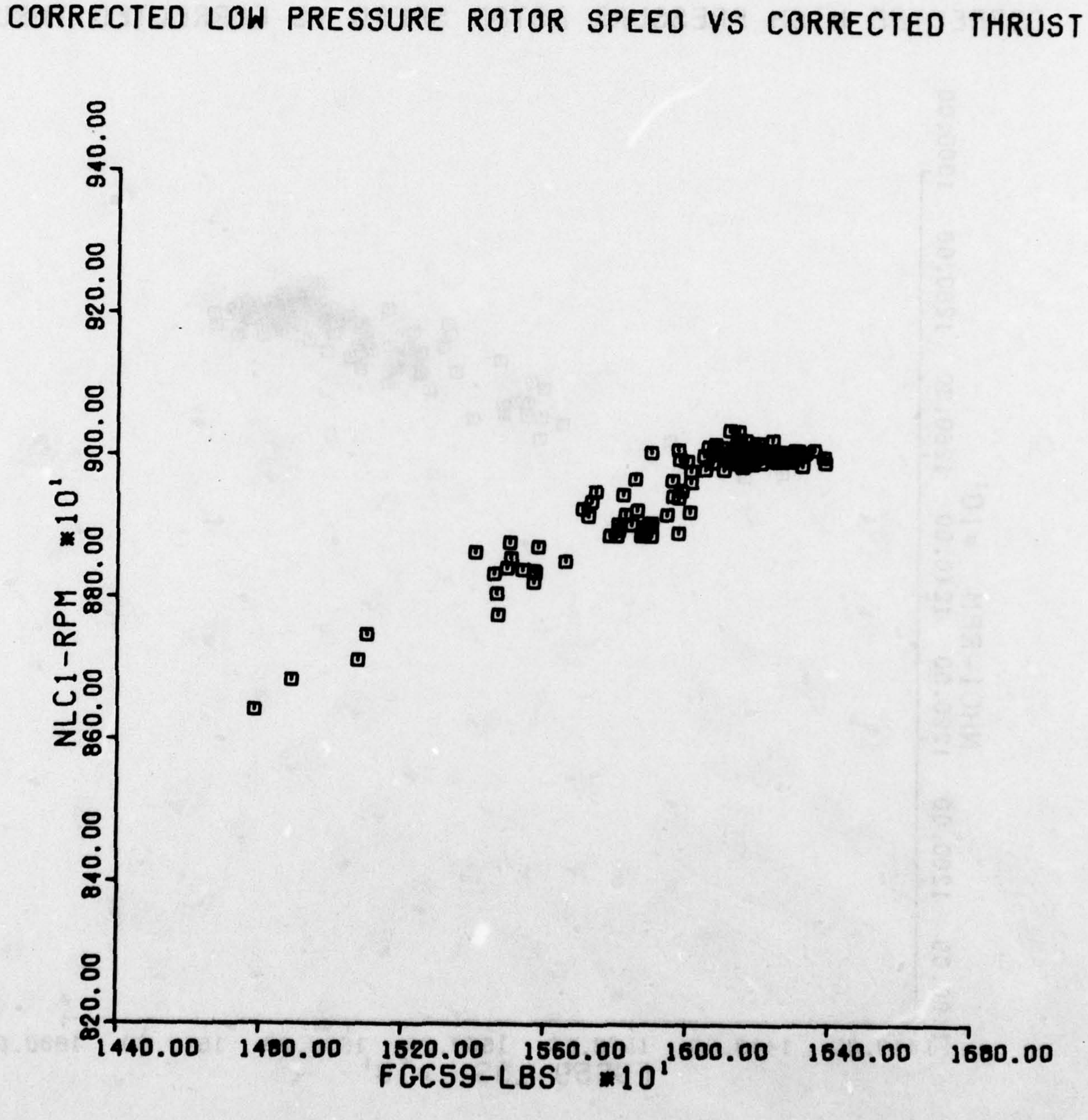


Figure 16 Corrected Low Pressure Rotor Speed versus Corrected Thrust

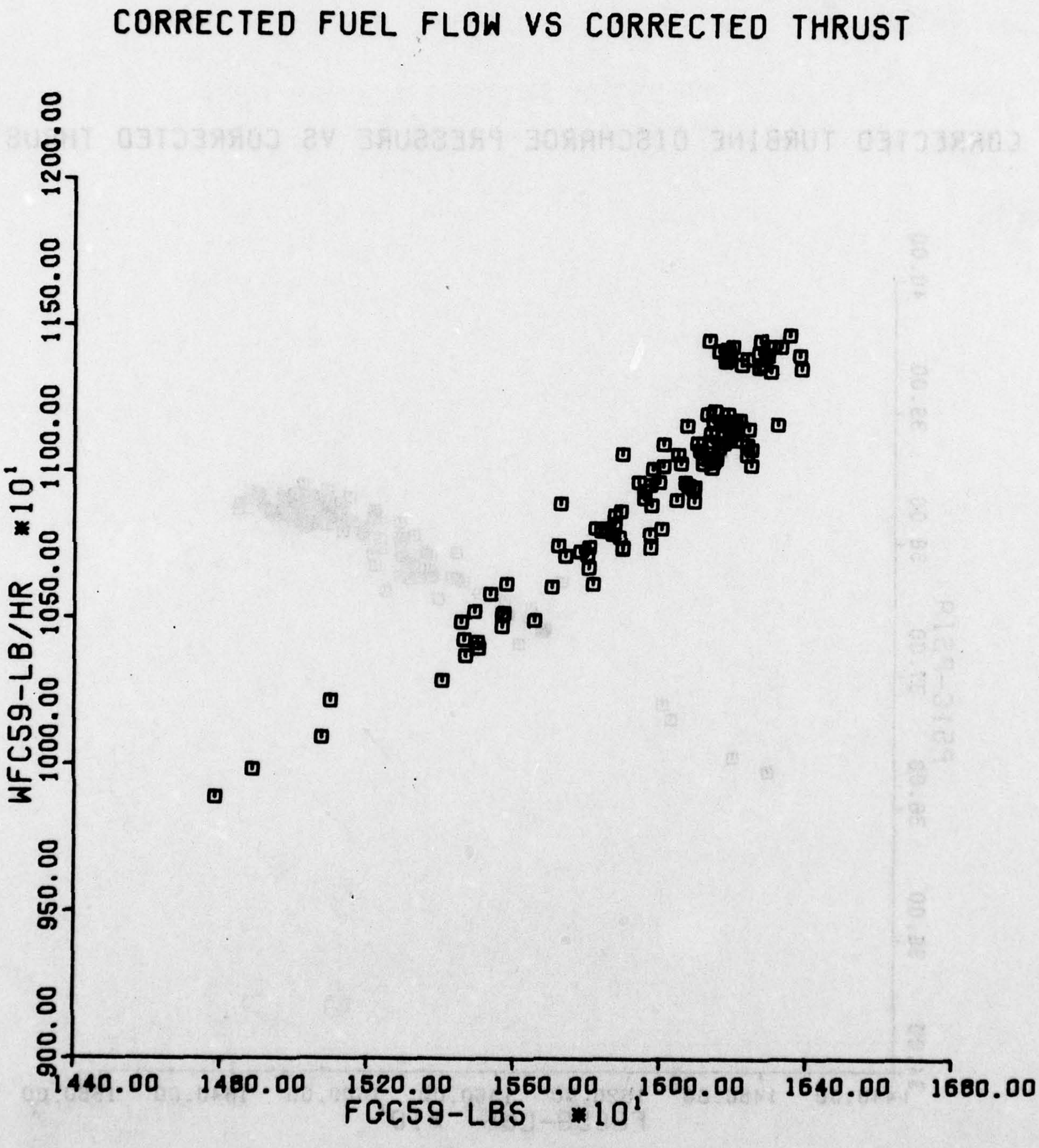


Figure 17 Corrected Fuel Flow versus Corrected Thrust

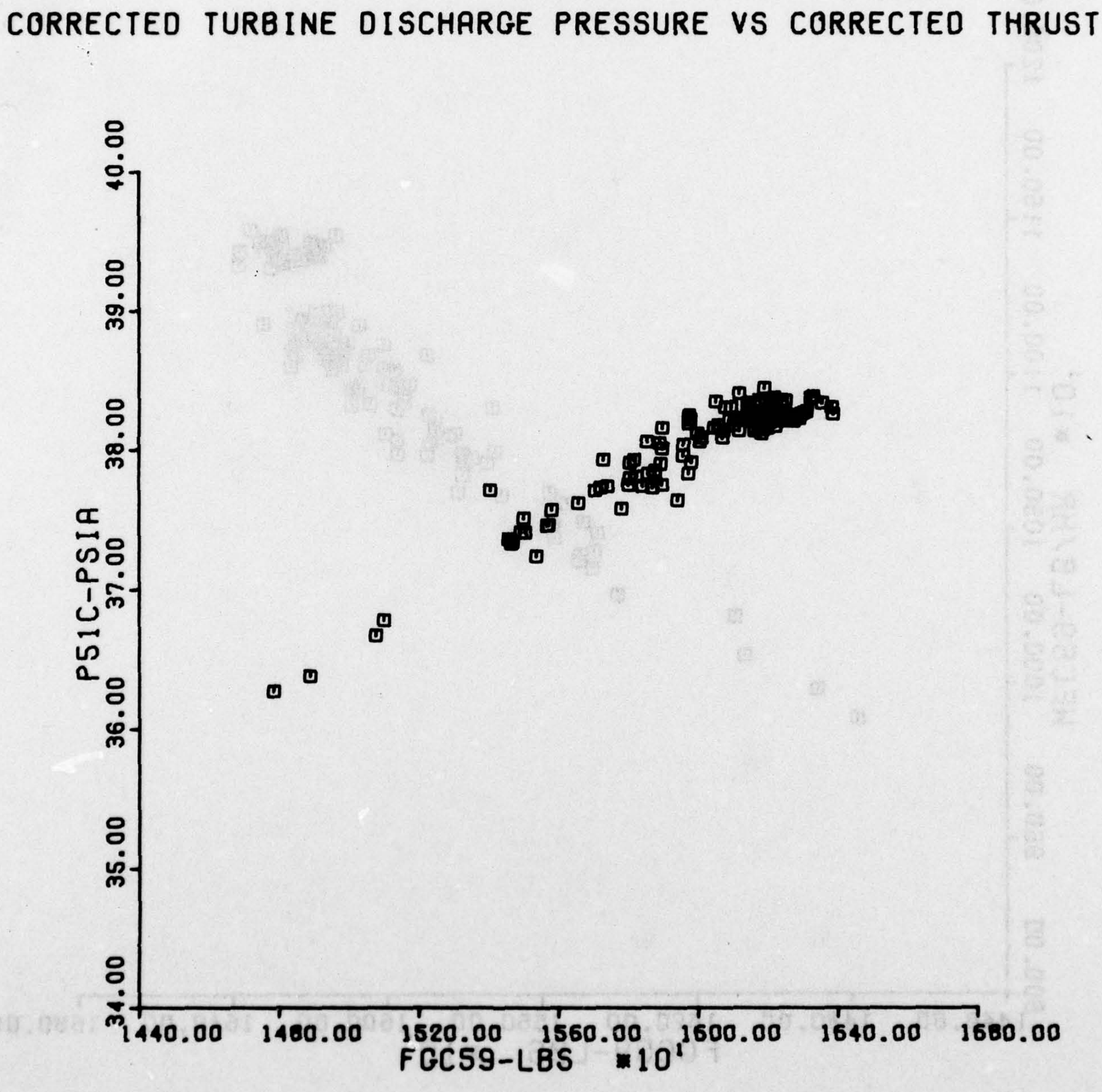


Figure 18 **Corrected Turbine Discharge Pressure versus Corrected Thrust**

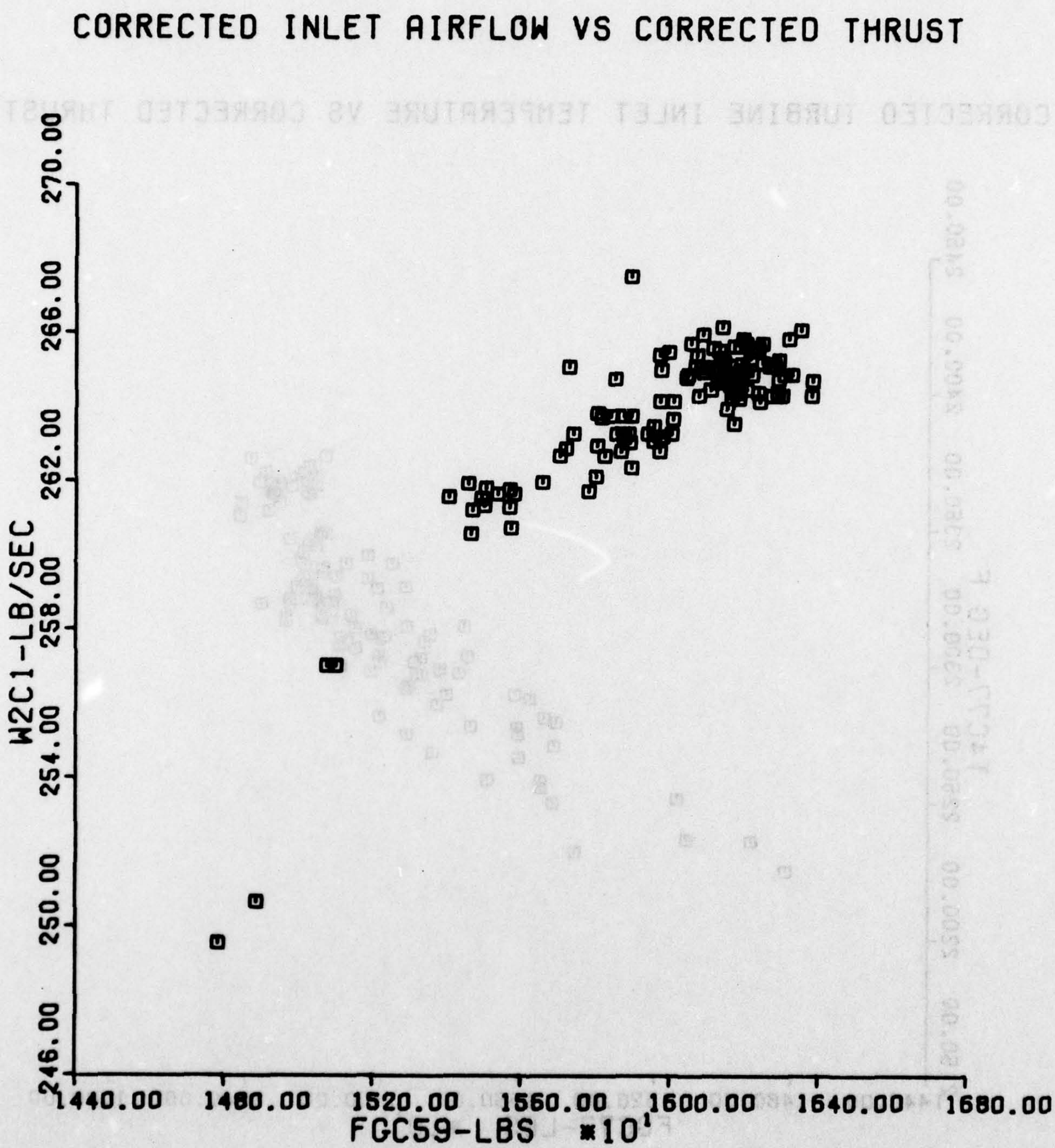


Figure 19 Corrected Inlet Airflow versus Corrected Thrust

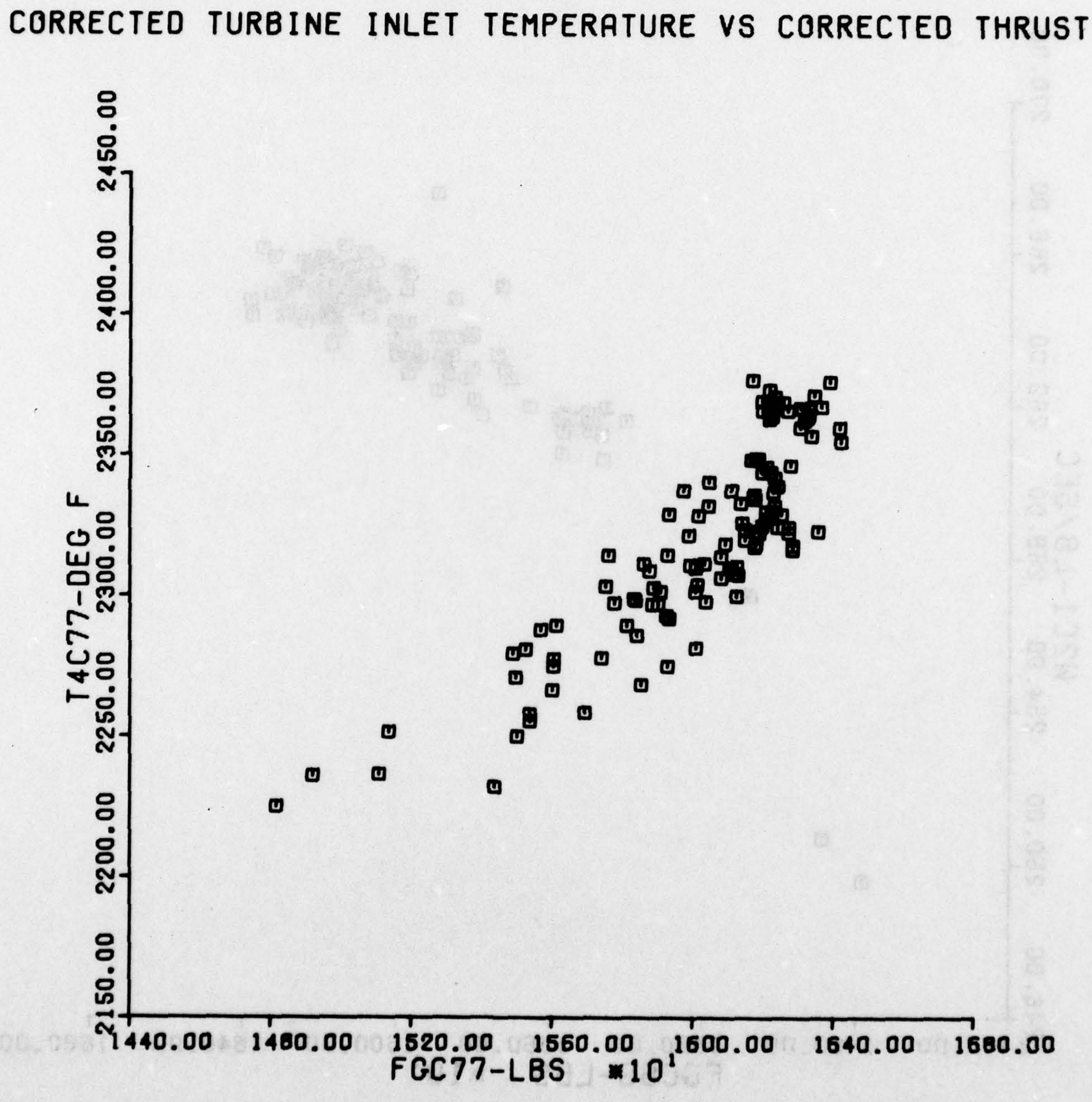


Figure 20 **Corrected Turbine Stator Inlet Temperature versus Corrected Thrust**

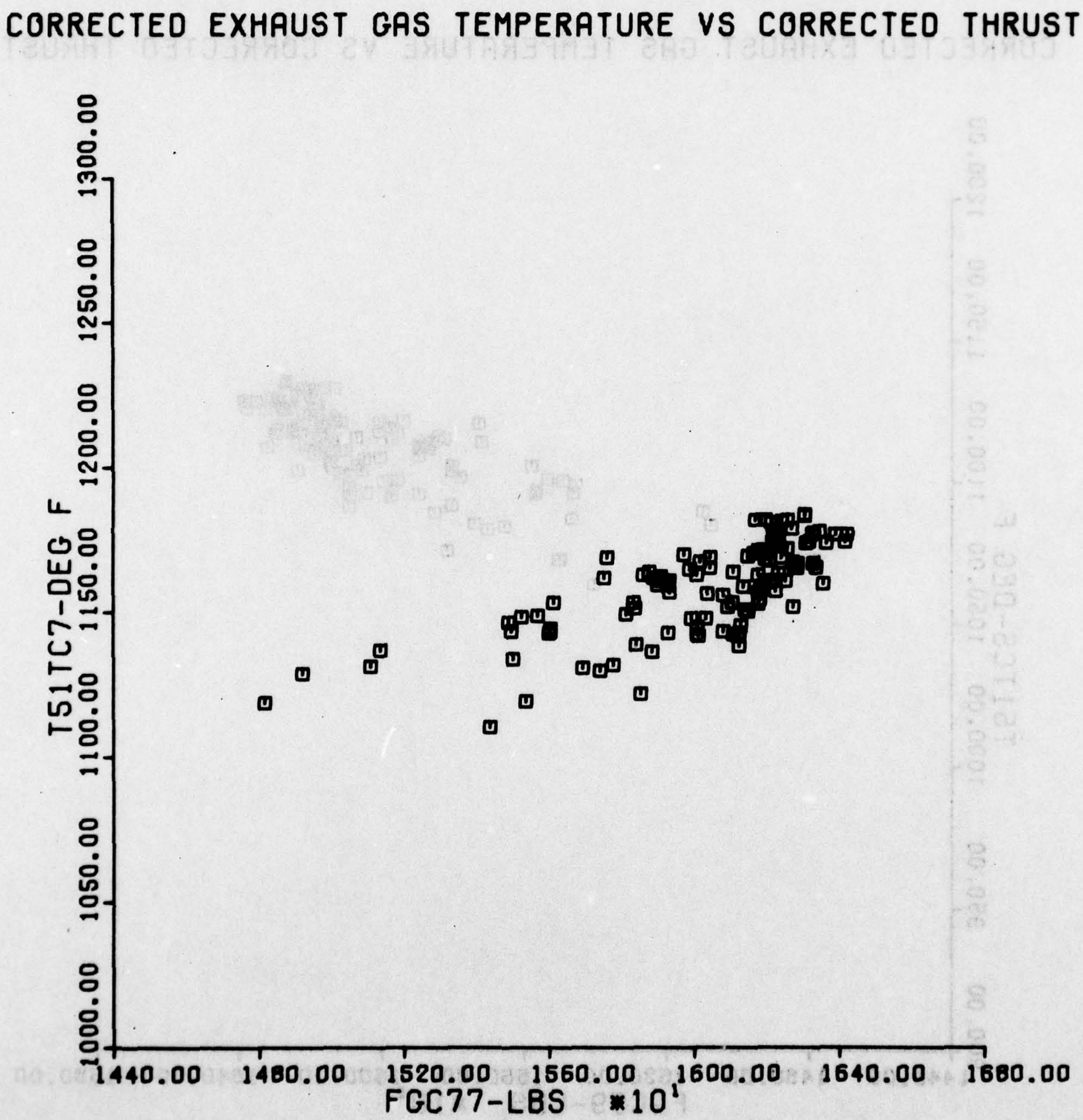


Figure 21 Corrected Exhaust Gas Temperature versus Corrected Thrust

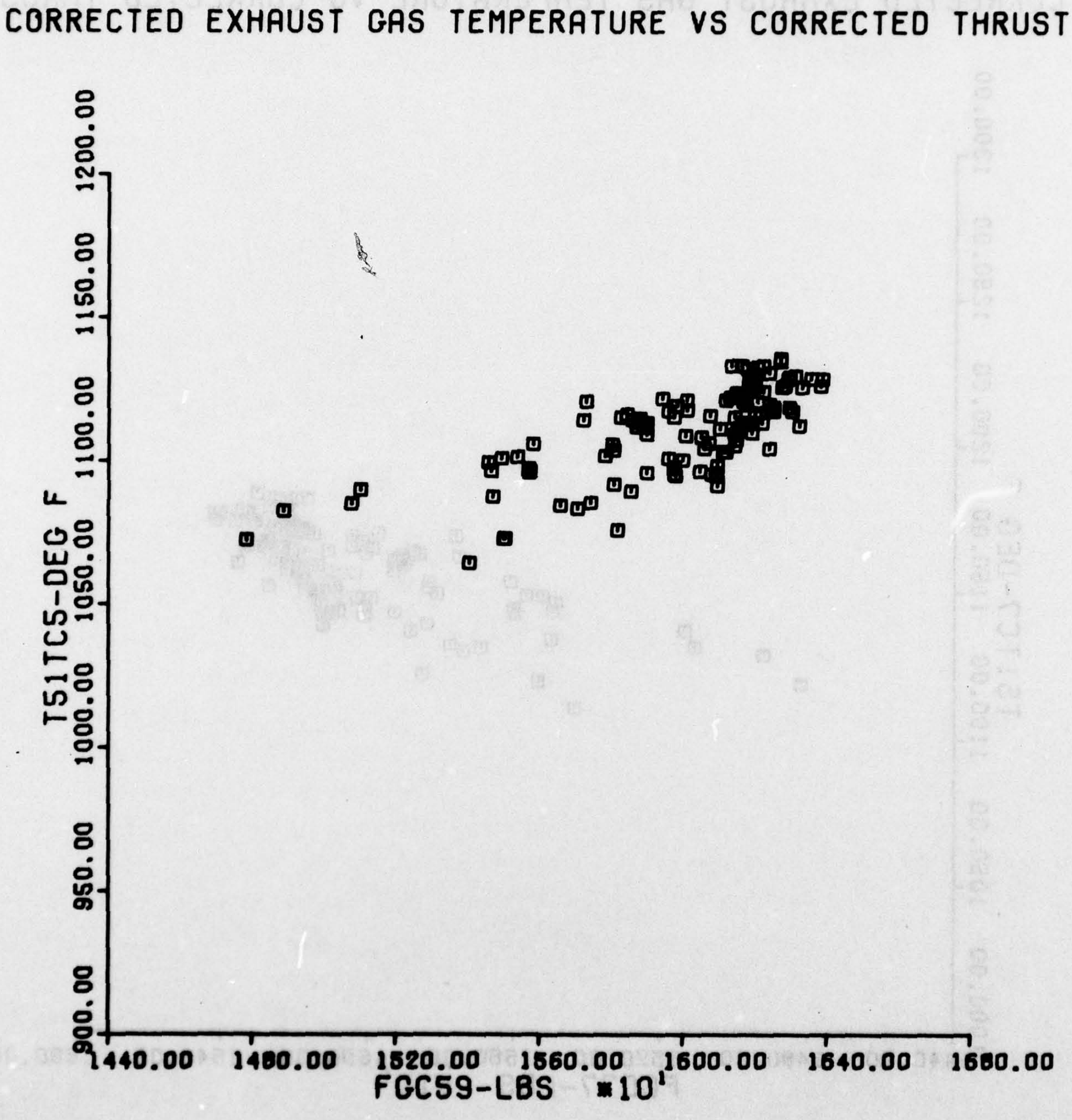


Figure 22 Corrected Exhaust Gas Temperature versus Corrected Thrust

it on the CRT, and records it on the line printer, introduces a certain amount of random scatter due to the limited word storage size which limits the number of significant figures available. This problem appears to be most pronounced with thermocouple readings where a $\pm$ 6^{o}F "bounce" is introduced and is observable on the CRT display. An obvious solution to this problem would be to take many readings over a given time span and average them. However, this is not feasible since data can only be recorded at a once per minute rate and the engine takes nearly five of the six available minutes to stabilize. Despite this problem the data appears to show less scatter than data from previous TF41 AMT tests run at the Propulsion Laboratory (Ref. 3). Some other prime contributions to the data scatter are the engine deterioration itself and also the varying customer bleed flow rates. Even with the scatter, the trends shown by these plots are typical of a TF41, and confirm that the engine was operating properly throughout the test until failure.

MAXIMUM POWER PERFORMANCE DETERIORATION

One of the primary objectives of this test was to quantify engine performance deterioration under realistic usage conditions. In past tests, one approach has been to track maximum power thrust (recorded during the six minute "flat" of each A cycle) as a function of engine operating time. One of the problems with this approach is that thrust is a function of ambient temperature and in Propulsion Laboratory Facilities there is no control over inlet air temperature. Therefore, a search of the data must be made to determine an ambient condition with a reasonable spread in engine hours and enough data points to be able to draw meaningful conclusions. Due to the very limited number of test hours (106) there was a minimal amount of data available for this analysis. With this particular test, the problem was further compounded by the misset NH governor which was adjusted part way into the test (27 AMT hours). The control interference caused by the low governor setting had the effect of limiting performance below

maximum achievable levels. The varying 11th stage customer bleed also affected thrust. A search of the data from the 118 "A" cycles did not identify any ambient condition with a reasonable spread in operating time, the same customer bleed flow rate, and the same NH governor setting. Therefore, no conclusions could be drawn as to the impact of engine deterioration on maximum power performance. However, the part power performance calibration data can be used to infer some of the deterioration effects.

PERFORMANCE CALIBRATIONS

Steady state power calibrations were performed before the AMT test and after 100 AMT hours (132 total test hours). The engine was allowed to stabilize for at least 5 minutes before data was recorded at four or five power settings between 8500 pounds thrust and intermediate power. The data was then corrected according to the procedures outlined in Appendix A. Note that the two calibrations were performed at different mass flow limiter trims which impact maximum power thrust levels. The pre-endurance calibration was run at 45°F inlet temperature with the nominal mass flow limiter trim and the 100 AMT hour calibration was run at 20°F with the trimmed up mass flow limiter.

Figures 23 and 24 compare the AFAPL pre-test performance calibrations with Allison's "as shipped" performance data. In general the AFAPL data compares very well with Allison's. The one exception appears to be corrected high pressure rotor speed. Allison's high pressure rotor speeds are consistently 1/2% higher than the AFAPL data.

Figures 25 through 34 present plots of the corrected data for the two steady state power calibrations. In an effort to aid in the interpretation of this data, the percent change in each corrected parameter that occurred between each calibration run was calculated at two different thrust levels (13500 LBS and 11000 LBS). This data is presented in Table 7.

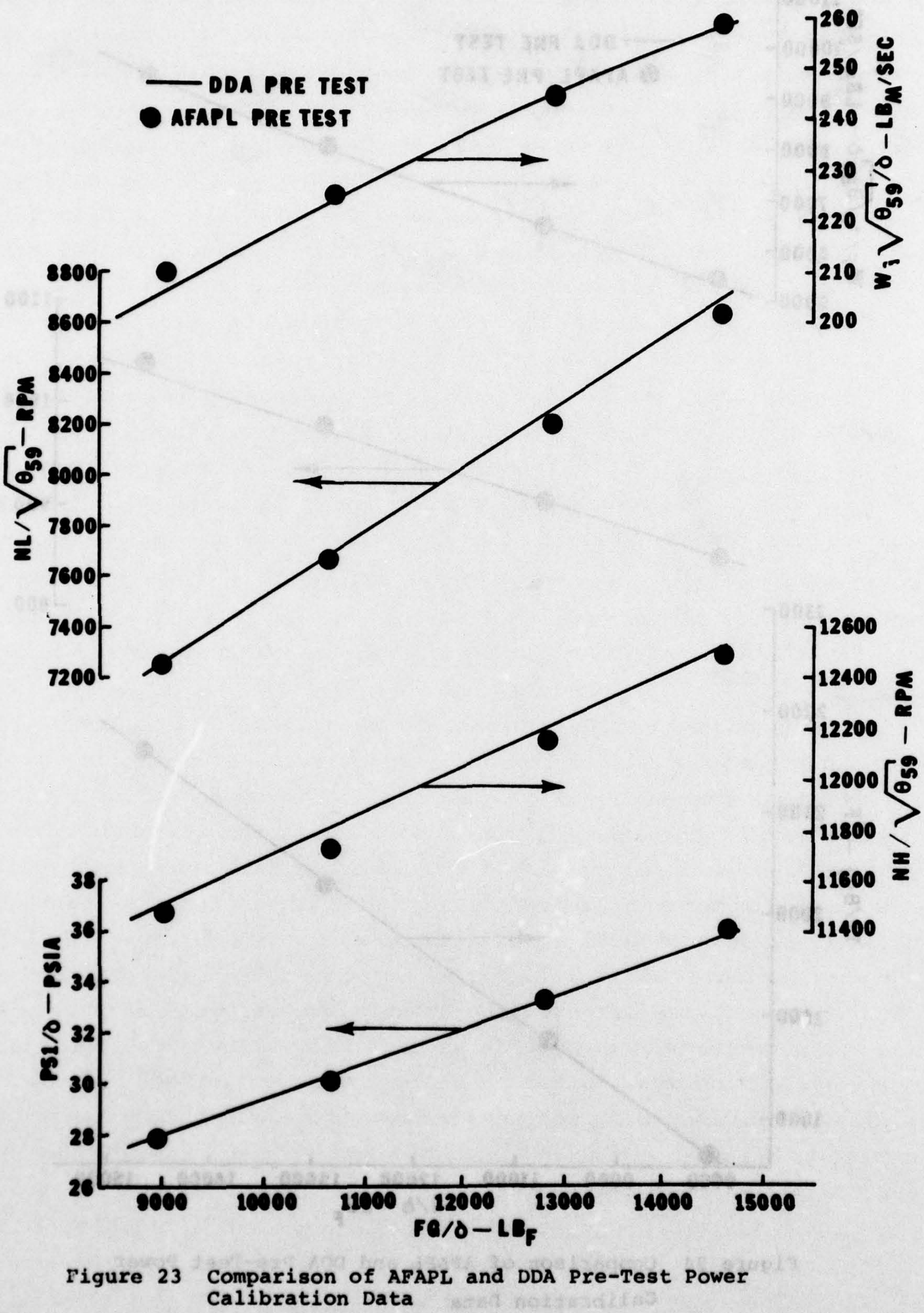


Figure 23 Comparison of AFAPL and DDA Pre-Test Power Calibration Data

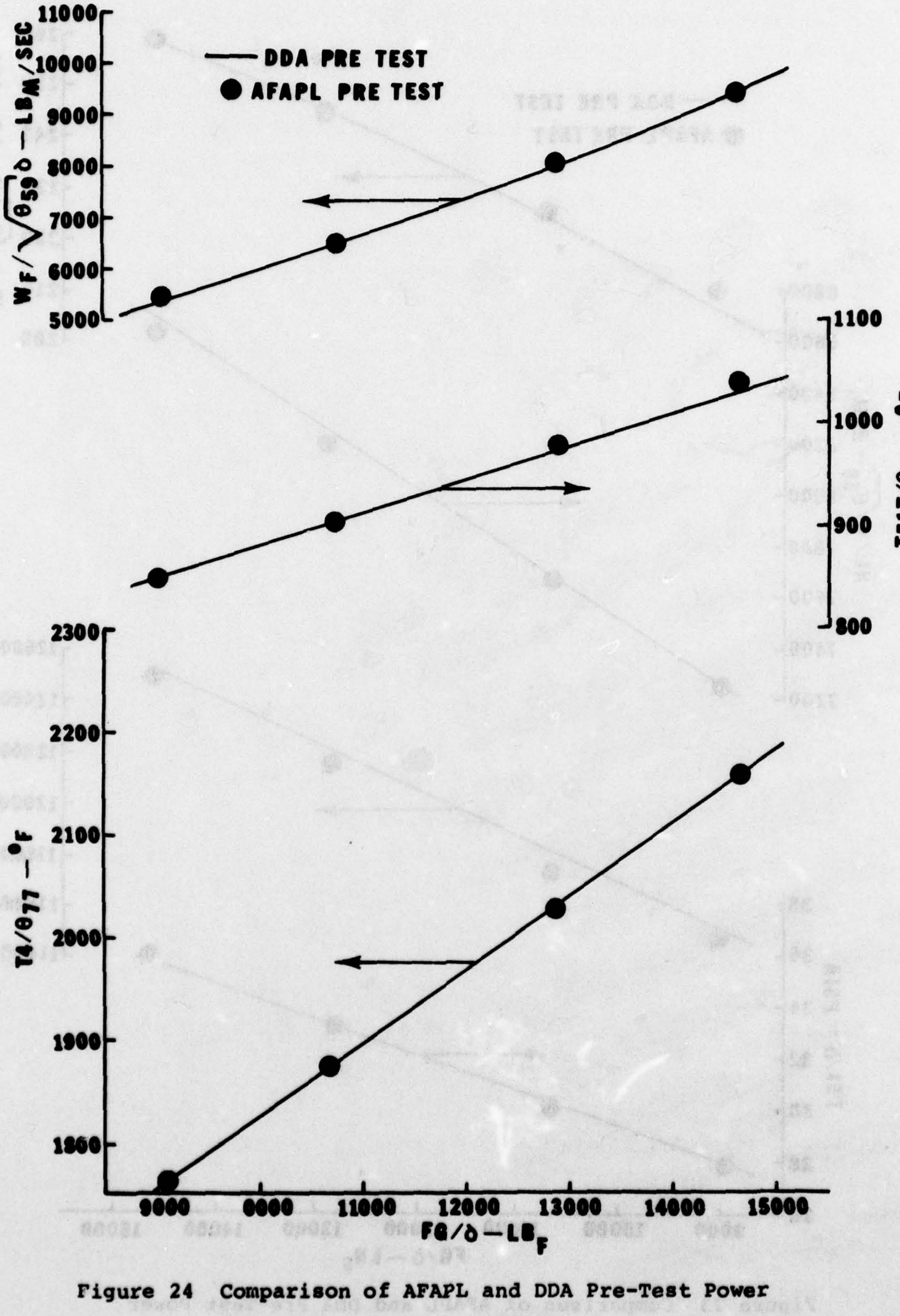


Figure 24 Comparison of AFAPL and DDA Pre-Test Power Calibration Data

TABLE 7 CHANGES IN PERFORMANCE PARAMETERS WITH OPERATING TIME AT SELECTED THRUST LEVELS

PARAMETER	13500 LB	11000 LB
Corrected Turbine Inlet Temp, T4C77	+ .9%	+1.2%
Corrected H.P. Rotor Speed, NHC1	- .4%	- .3%
Corrected Exhaust Gas Pres., P51C	0	0
Corrected L.P. Rotor Speed, NLC1	- .6%	- .5%
Corrected Fuel Flow, WFC59	+1.8%	+2.3%
Corrected Airflow, W2C1	-1.2%	-1.1%
Corrected Exhaust Gas Temp, T51T77	+ .4%	+ .6%

CORRECTED L. P. ROTOR SPEED VS CORRECTED THRUST

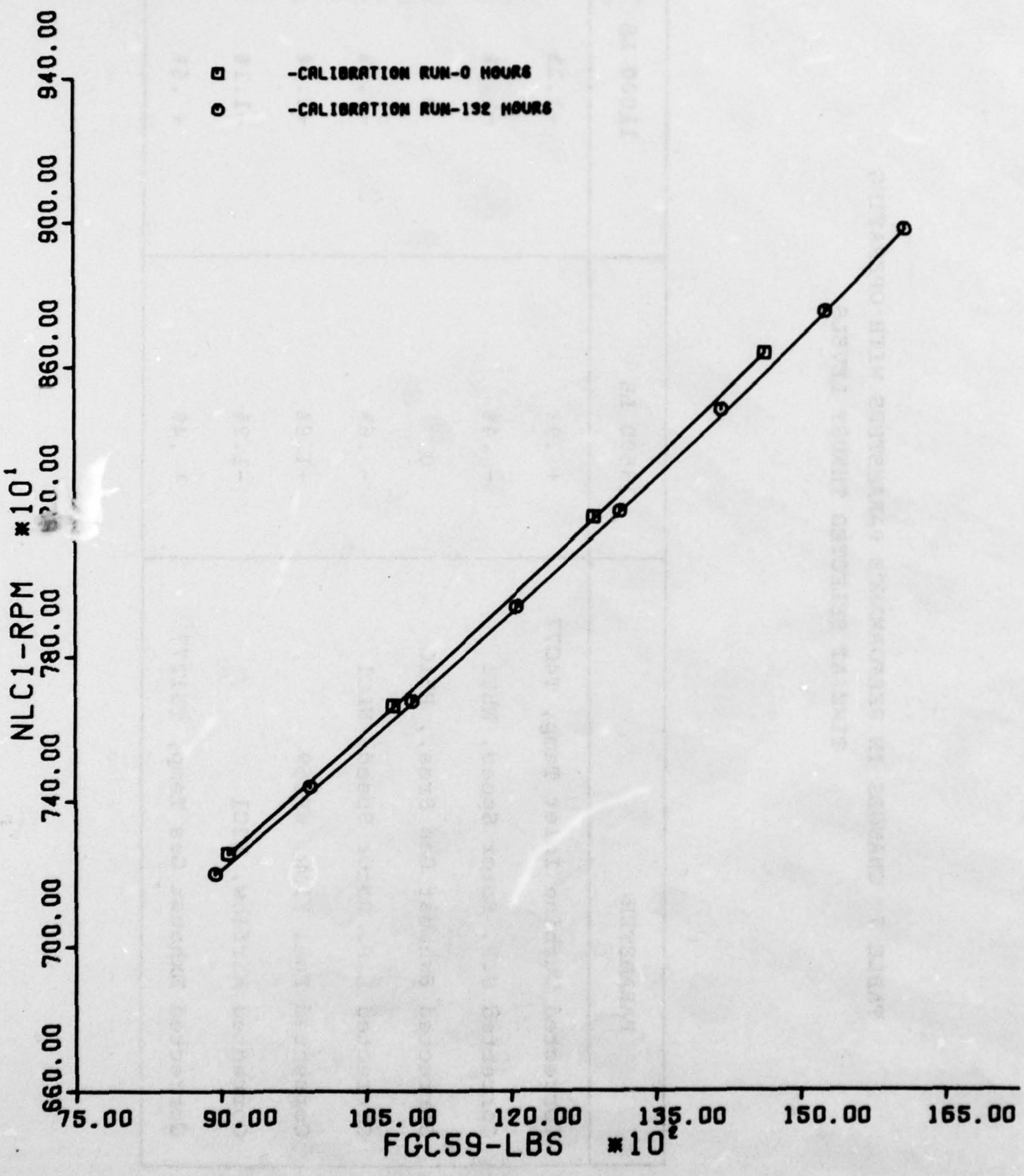


Figure 25 Corrected L.P. Rotor Speed versus Corrected Thrust

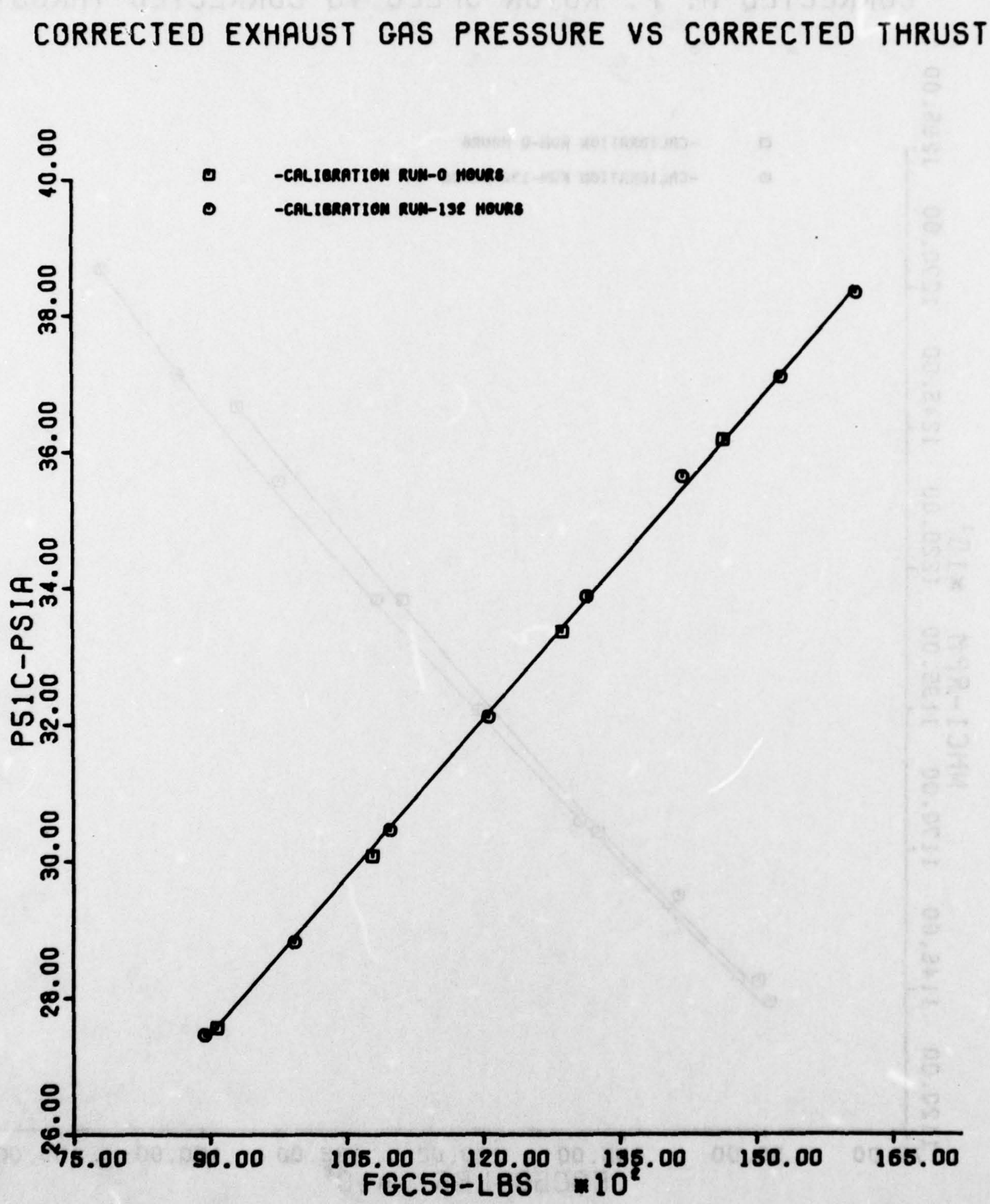


Figure 26 Corrected Exhaust Gas Pressure versus Corrected Thrust

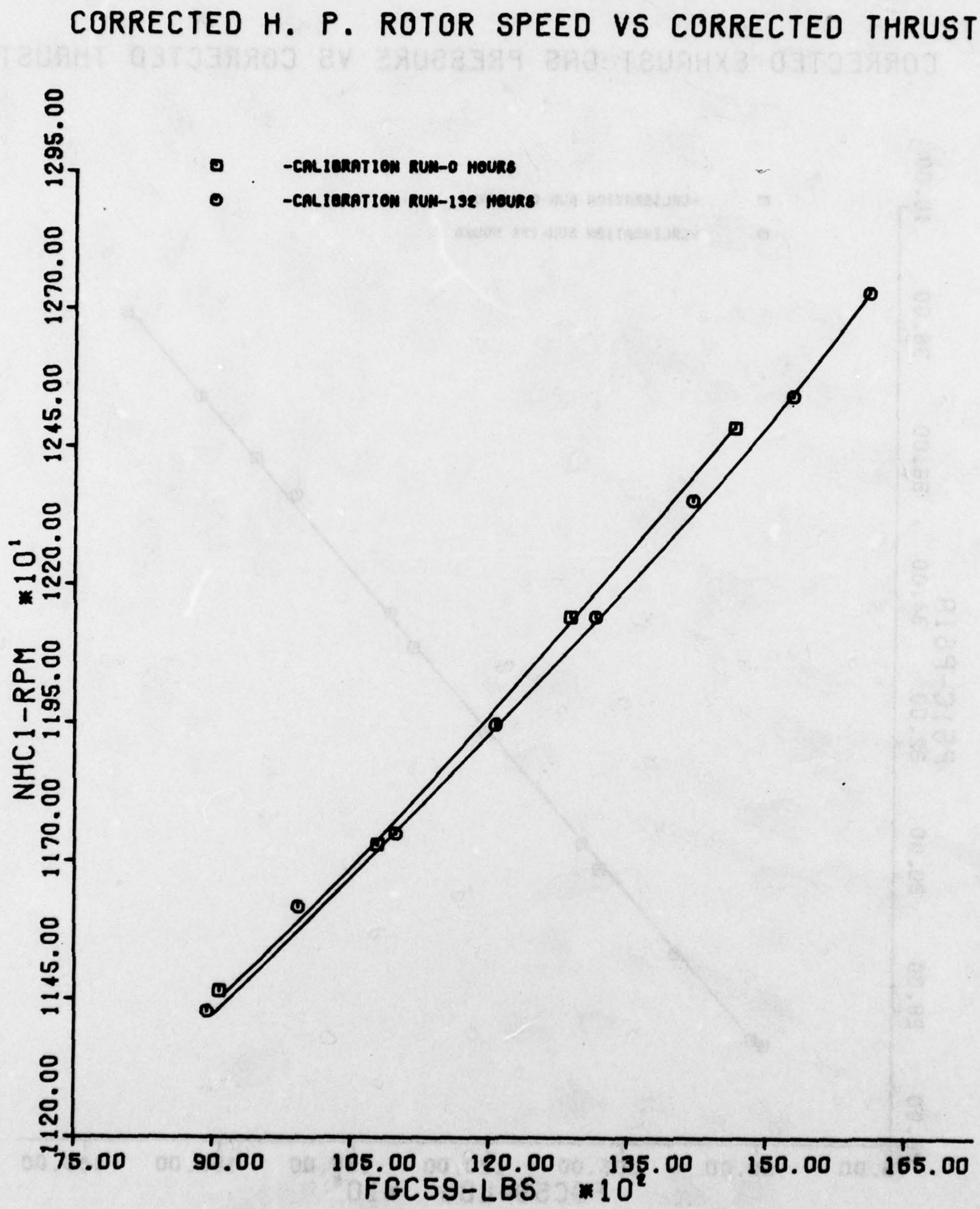


Figure 27 Corrected H.P. Rotor Speed versus Corrected Thrust

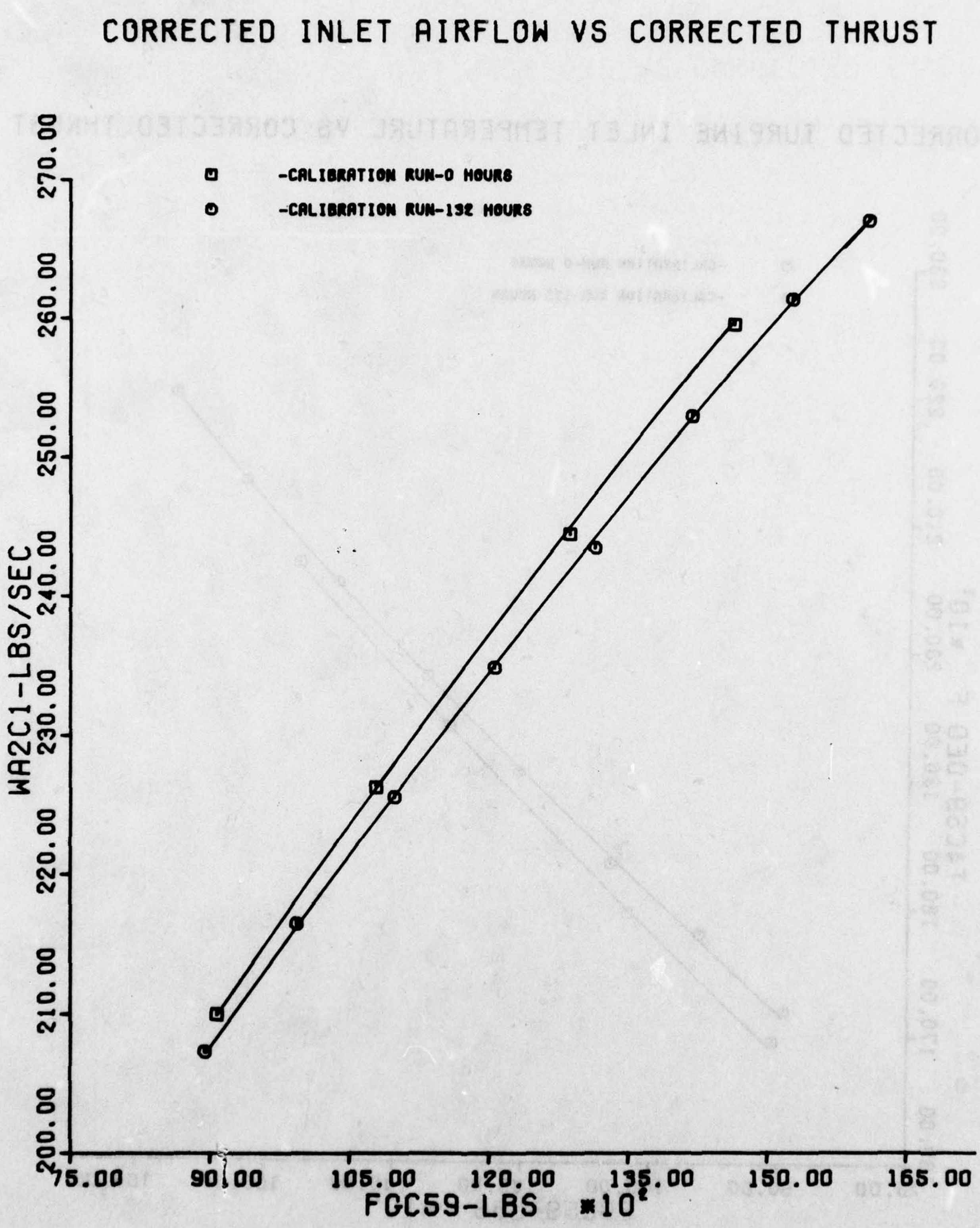


Figure 28 Corrected Inlet Airflow versus Corrected Thrust

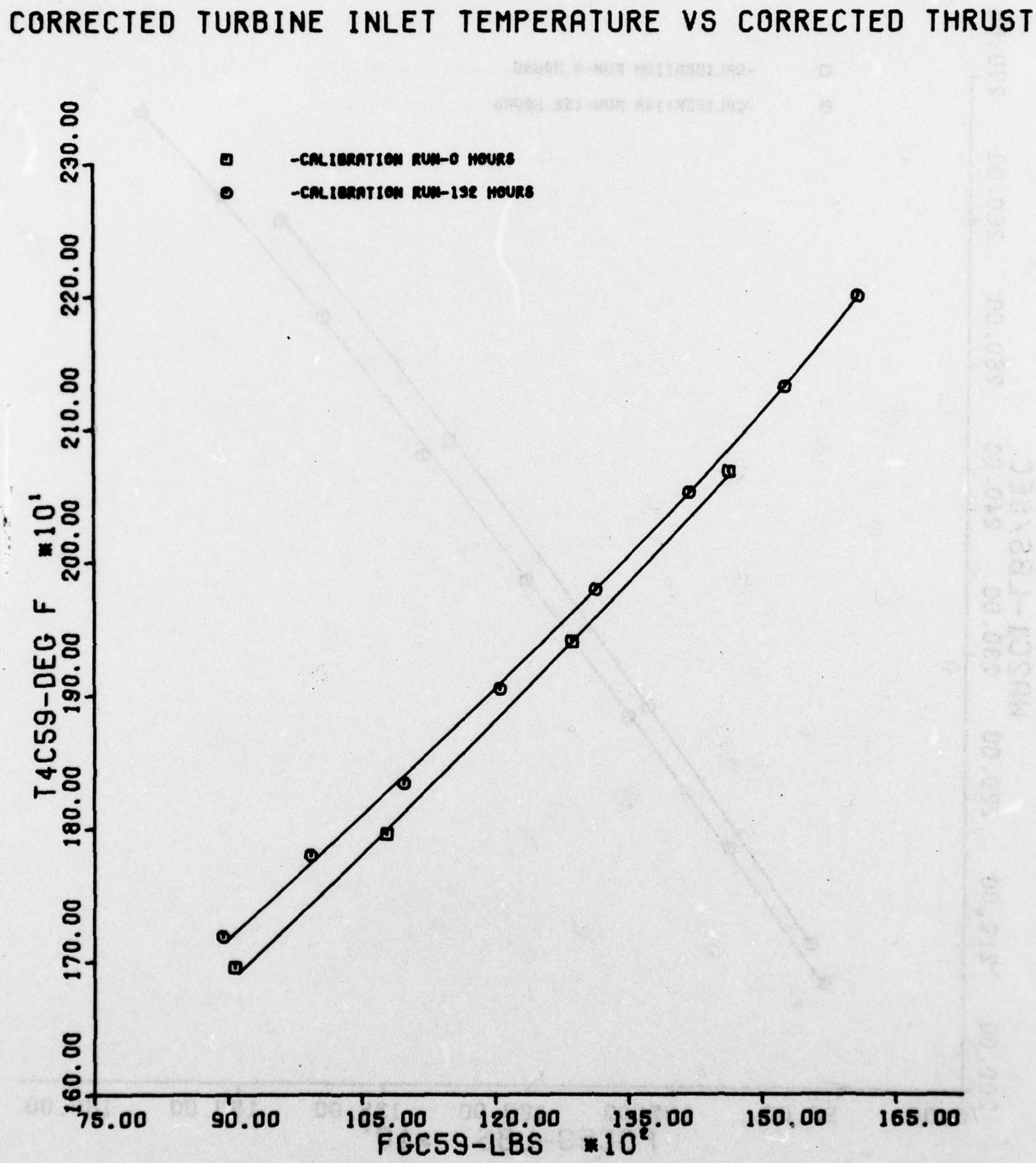


Figure 29 Corrected Turbine Stator Inlet Temperature versus Corrected Thrust

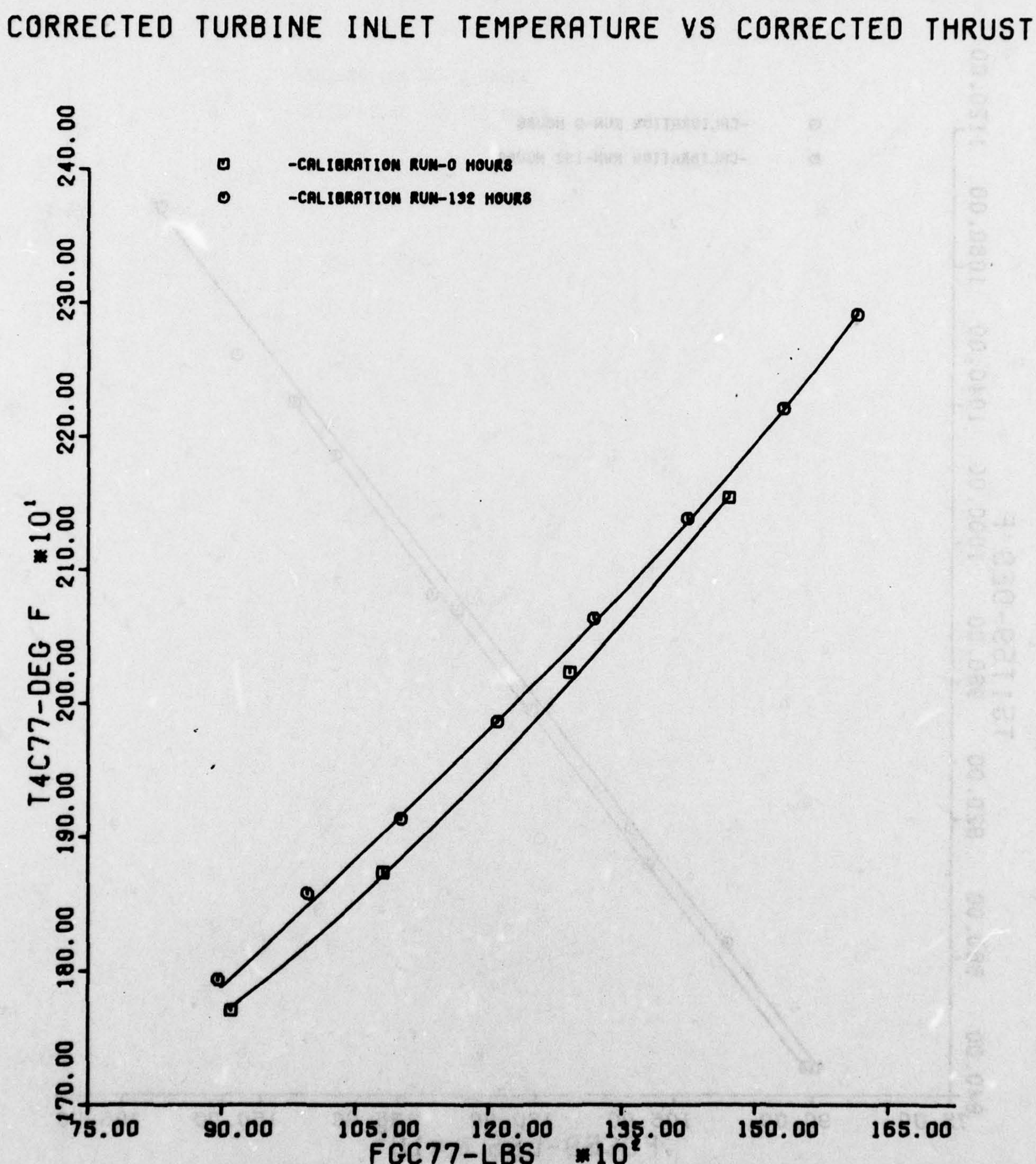


Figure 30 Corrected Turbine Stator Inlet Temperature versus Corrected Thrust

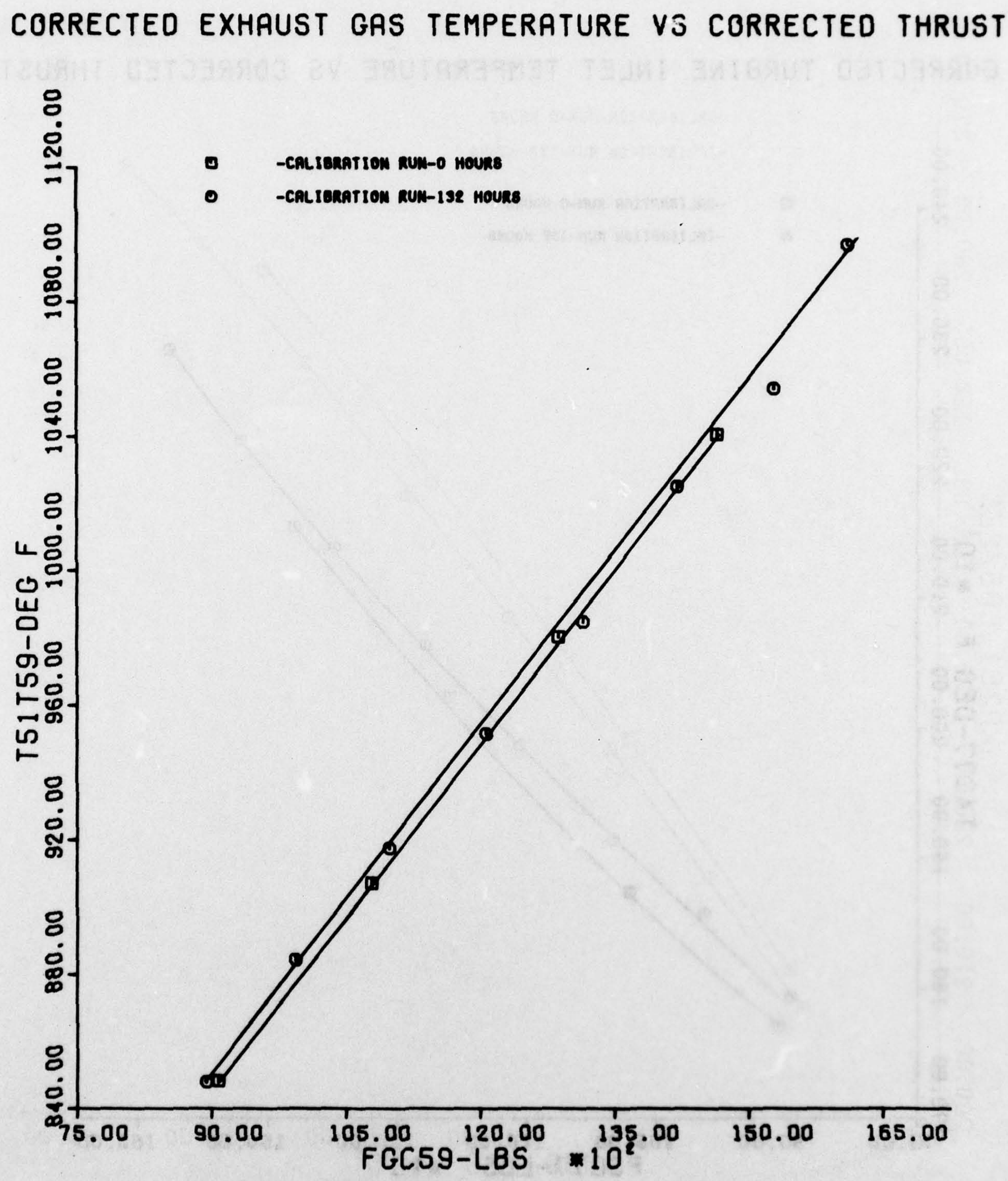


Figure 31 Corrected Exhaust Gas Temperature versus Corrected Thrust

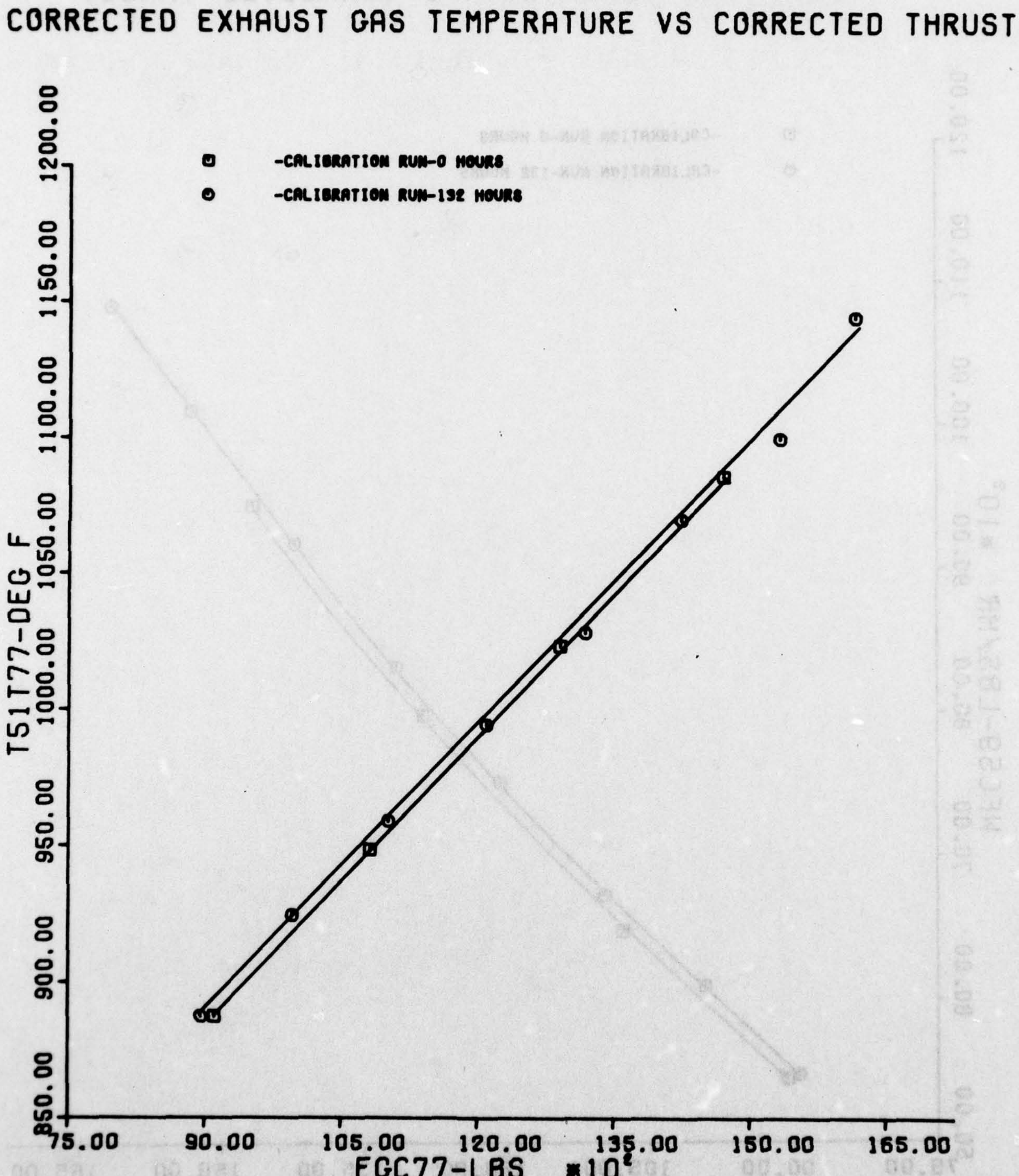


Figure 32 Corrected Exhaust Gas Temperature versus Corrected Thrust

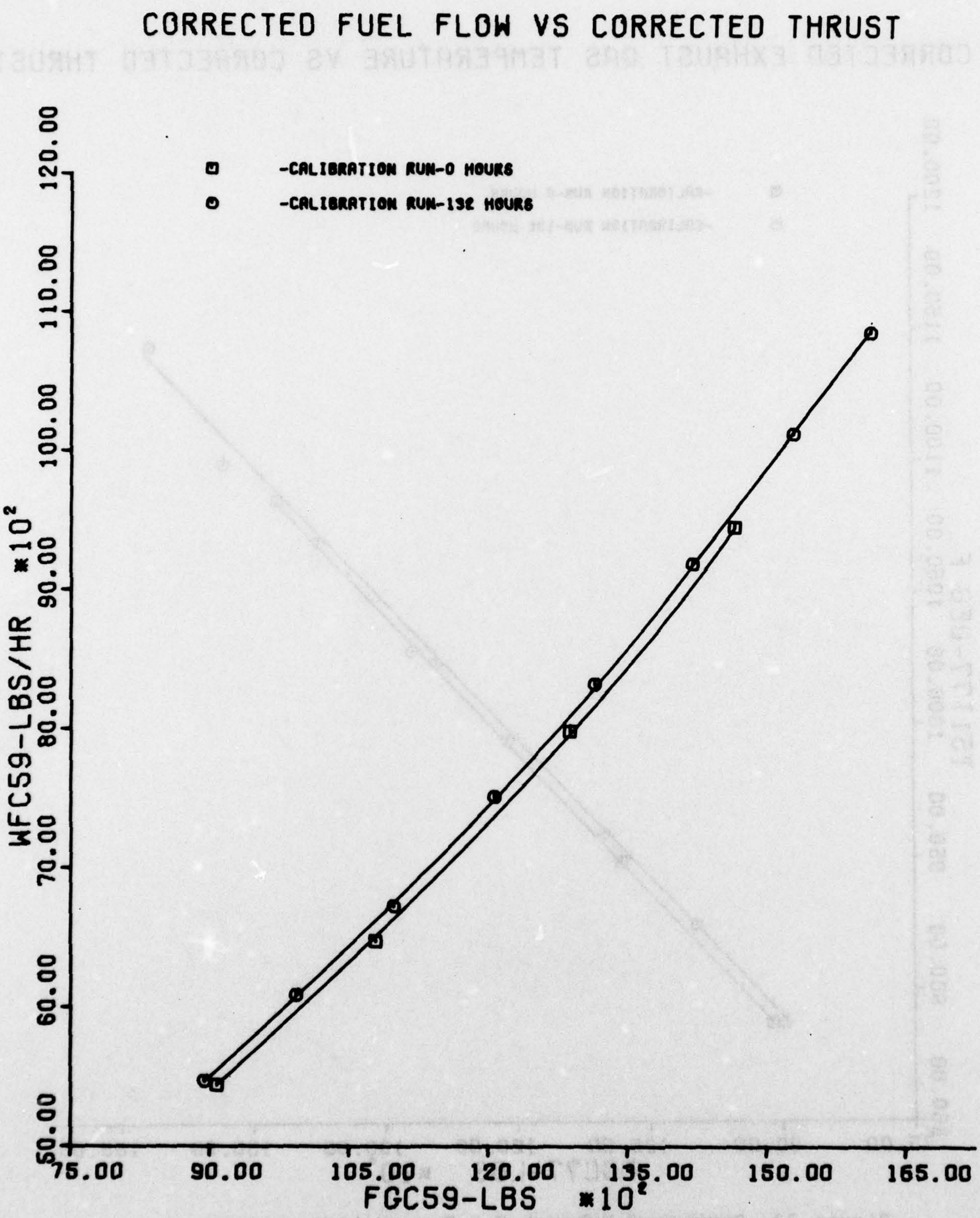


Figure 33 Corrected Fuel Flow versus Corrected Thrust

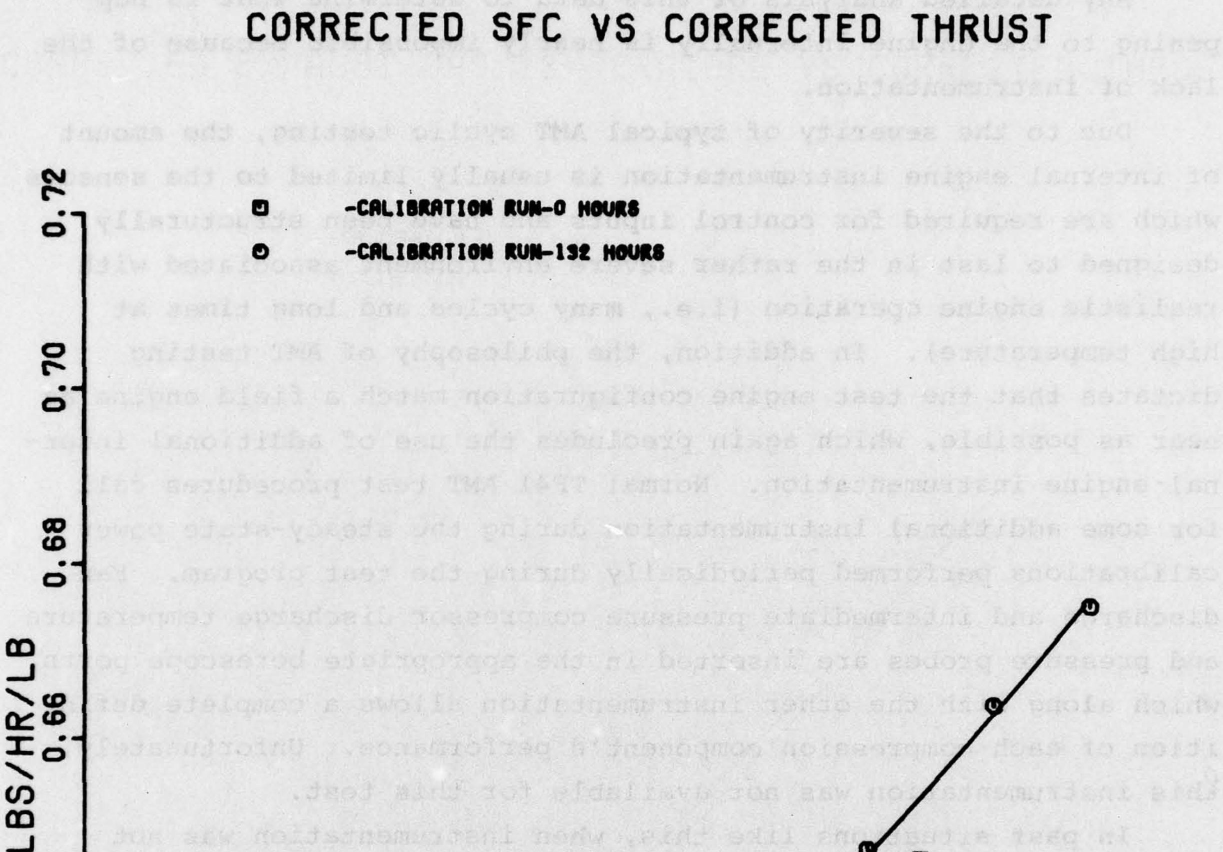


Figure 34 Corrected SFC versus Corrected Thrust

Any detailed analysis of this data to determine what is happening to the engine internally is nearly impossible because of the lack of instrumentation.

Due to the severity of typical AMT cyclic testing, the amount of internal engine instrumentation is usually limited to the sensors which are required for control inputs and have been structurally designed to last in the rather severe environment associated with realistic engine operation (i.e., many cycles and long times at high temperature). In addition, the philosophy of AMT testing dictates that the test engine configuration match a field engine as near as possible, which again precludes the use of additional internal engine instrumentation. Normal TF41 AMT test procedures call for some additional instrumentation during the steady-state power calibrations performed periodically during the test program. Fan discharge and intermediate pressure compressor discharge temperature and pressure probes are inserted in the appropriate borescope ports, which along with the other instrumentation allows a complete definition of each compression component's performance. Unfortunately, this instrumentation was not available for this test.

In past situations like this, when instrumentation was not available a steady state TF41 performance computer simulation was used in conjunction with the available part power calibration test data to infer changes in internal engine operation (Ref. 3). The production engine simulation was modified to match the pre-test and post-test performance data and then changes in important engine performance parameters which could not be measured in the test were estimated. This approach was not feasible here, because the deterioration effects were not yet pronounced enough after only 106 AMT hours to allow a computer analysis. The changes in corrected performance parameters are so small that it would be impossible to sort out measurement inaccuracies, modeling inaccuracies, and real deterioration effects. The computer model approach requires very definite deterioration trends in order to have any degree of confidence in the results.

However, some general observations on deterioration effects can be made. At a given thrust level, after 132 operating hours,

TF41 S/N 142163 ran at a slightly lower corrected low pressure rotor speed, a slightly lower high pressure rotor speed, at a higher turbine inlet temperature and exhaust gas temperature, at slightly reduced corrected airflow, with about the same exhaust gas pressure and with a higher fuel consumption. These trends are consistent with the performance rematch that has been seen in previous TF41 AMT engines as a result of reduction in turbine efficiency. Historically this loss is the prime contributor to engine performance deterioration and is probably responsible in this case also. However, the magnitude of the deterioration in this particular engine does not seem very severe.

It is interesting to note that on cold day operation (i.e., operation on the mass flow limiter) the engine's maximum power thrust actually increased as the engine deteriorated. At maximum power, the engine is controlled to a given corrected low pressure rotor speed. As it deteriorates though, turbine inlet temperature and exhaust gas temperature increase. This results in more thrust, but at the expense of a higher fuel consumption. Comparing the pre-test and 100 AMT hour calibration data at a corrected low pressure rotor speed of 8625 RPM (the original mass flow limiter setting) shows that engine 142163 increased thrust by about 1%. However, fuel flow went up nearly 4% to gain the additional 1% in performance.

VIII. RESULTS OF TEARDOWN INSPECTION AND FAILURE INVESTIGATION

Approximately 106 hours into the scheduled 263 hour AMT test, at intermediate power, a ball of flame was observed out the tail-pipe. Simultaneously, turbine vibration alarm limits and exhaust gas temperature limits were exceeded. The engine was shutdown. Visual inspection of the second stage low pressure turbine revealed considerable damage. The high pressure rotor was siezed and could not be turned by hand. The engine was removed from the cell and returned to Allison for a failure investigation.

At Allison the engine was torn down to its major modules. The details of the teardown inspection are contained in Appendix C. A brief summary of the major findings follows:

- L.P. Turbine (Figures 35 through 38)
  - first and second stage blades - heavy damage
  - first and second stage vanes - heavy damage with pieces missing
  - bearing support fairing - heavy damage with dents, tears and gouges
- H.P. Turbine (Figures 39 and 40)
  - right-hand blade of #7 paired blades broken off in second stage wheel dovetail
  - second stage wheel dovetail had two pieces of wheel broken off on O.D., one piece on each side
  - H.P. thrust bearing intermediate seal insert seized on H.P. shaft
  - first stage blade - position 57 had fatigue crack failure in bottom serration on the pressure side

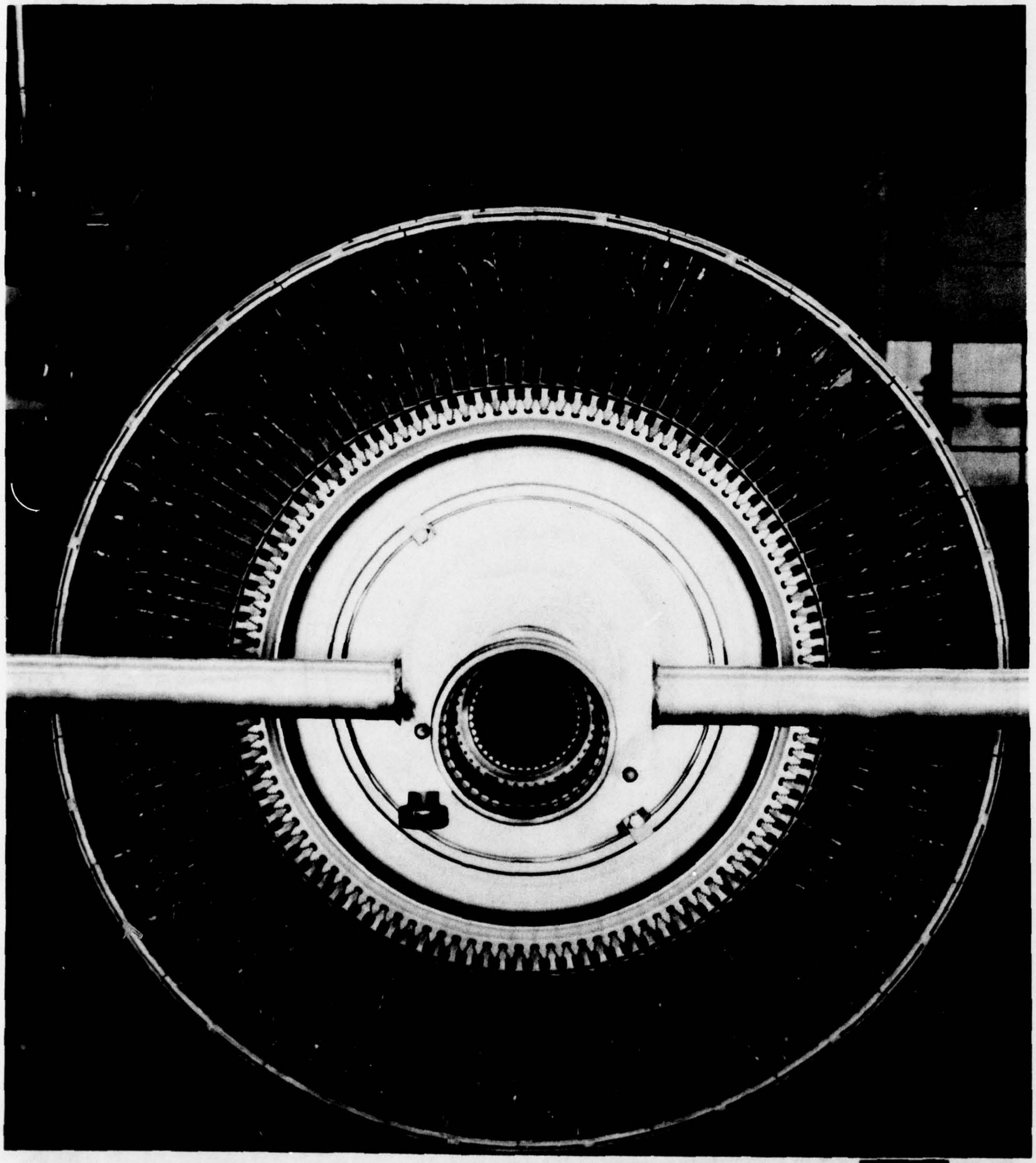


Figure 35   Front-First Stage L.P. Turbine Rotor 336185

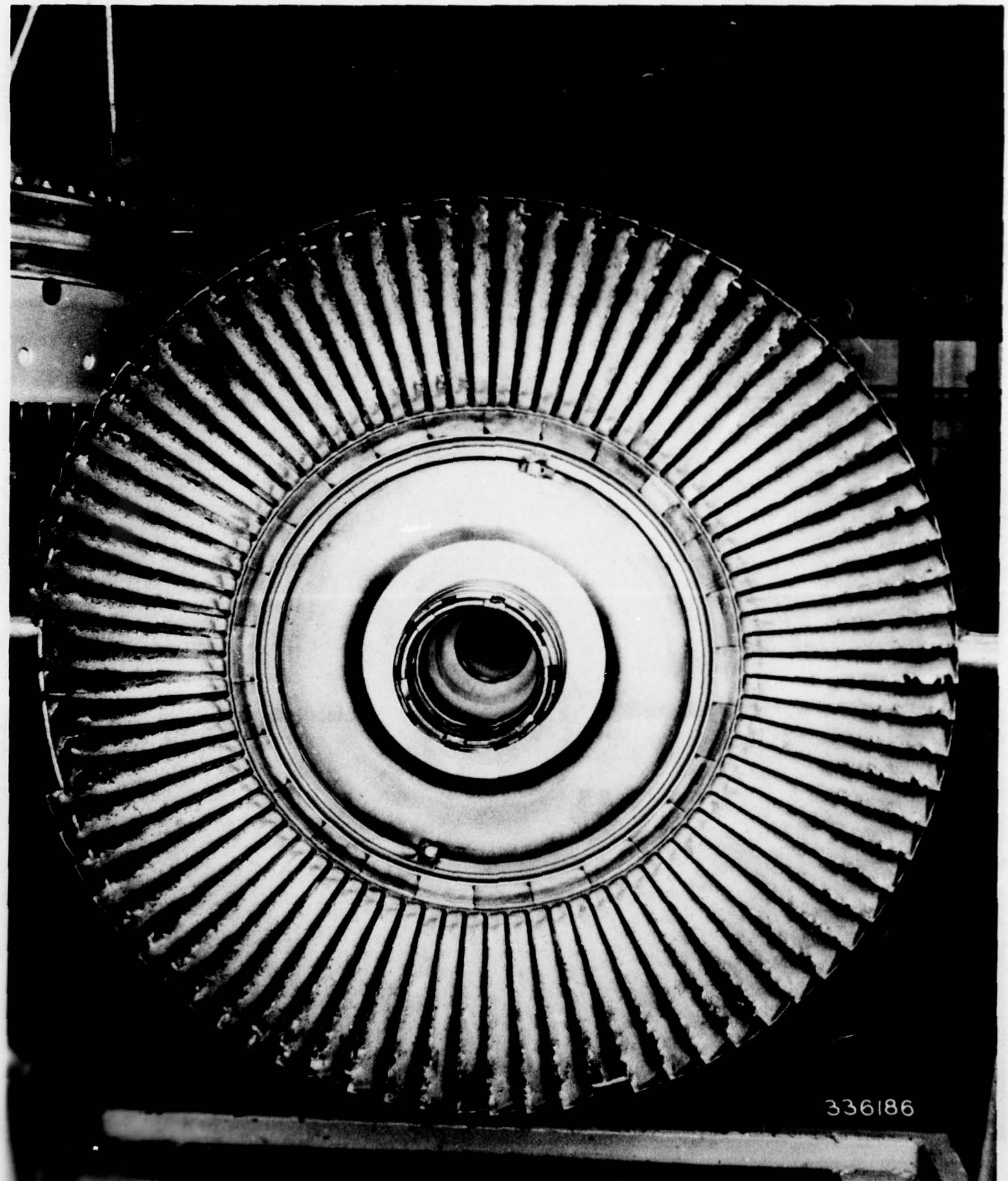


Figure 36   Rear-Second Stage L.P. Turbine Rotor

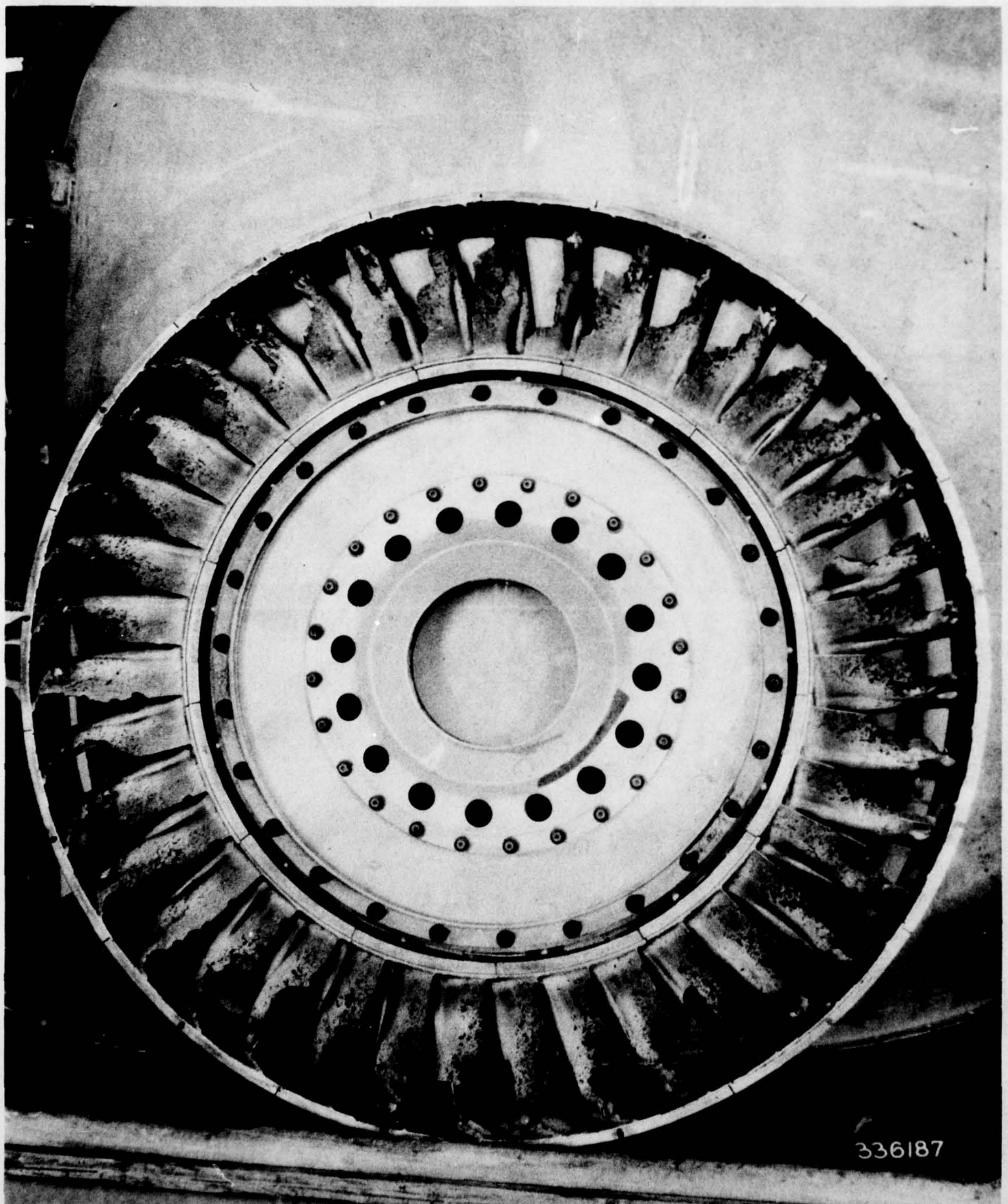


Figure 37 L.P. Turbine Inlet Stators

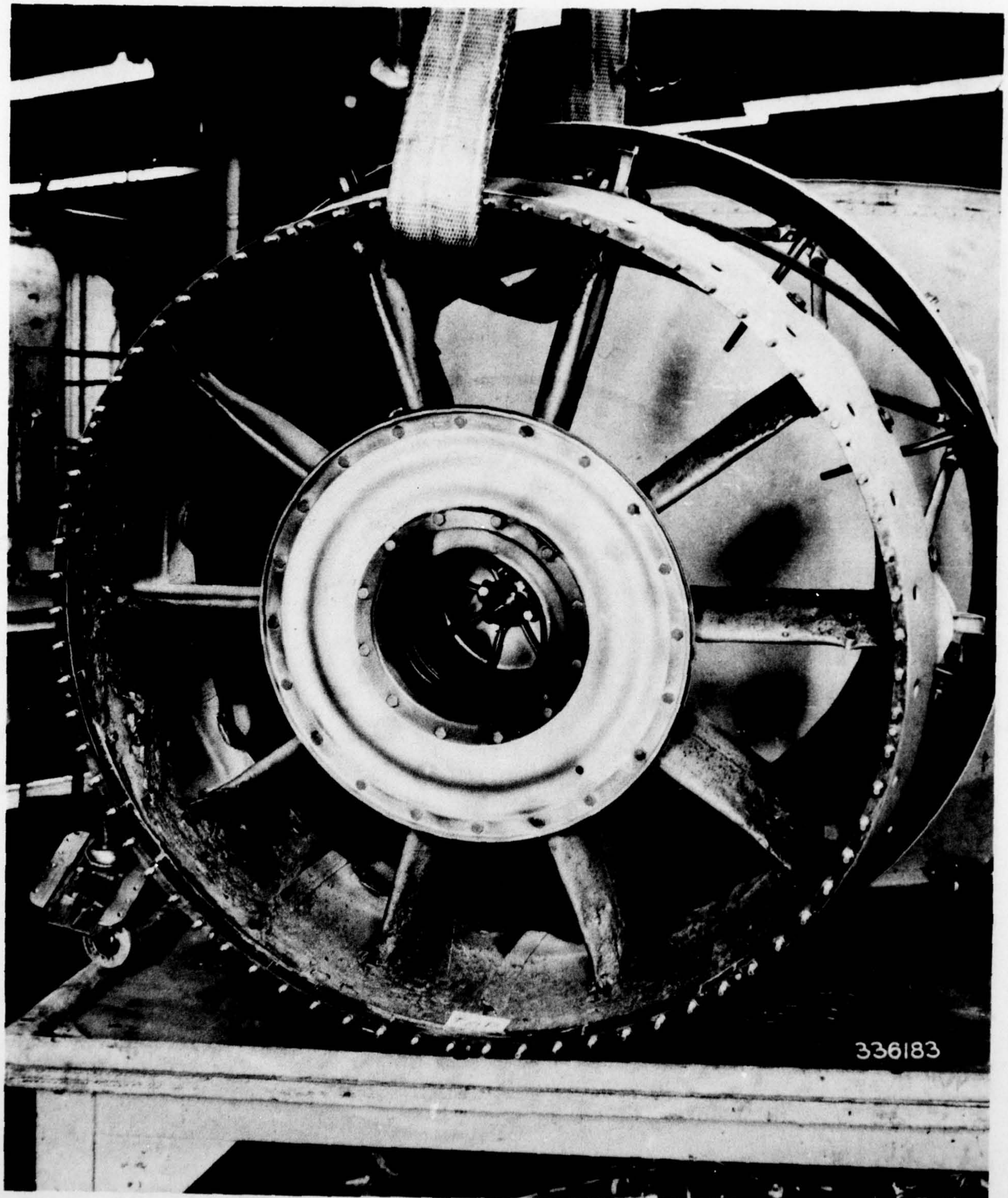


Figure 38 L.P. Turbine Bearing Support Fairing

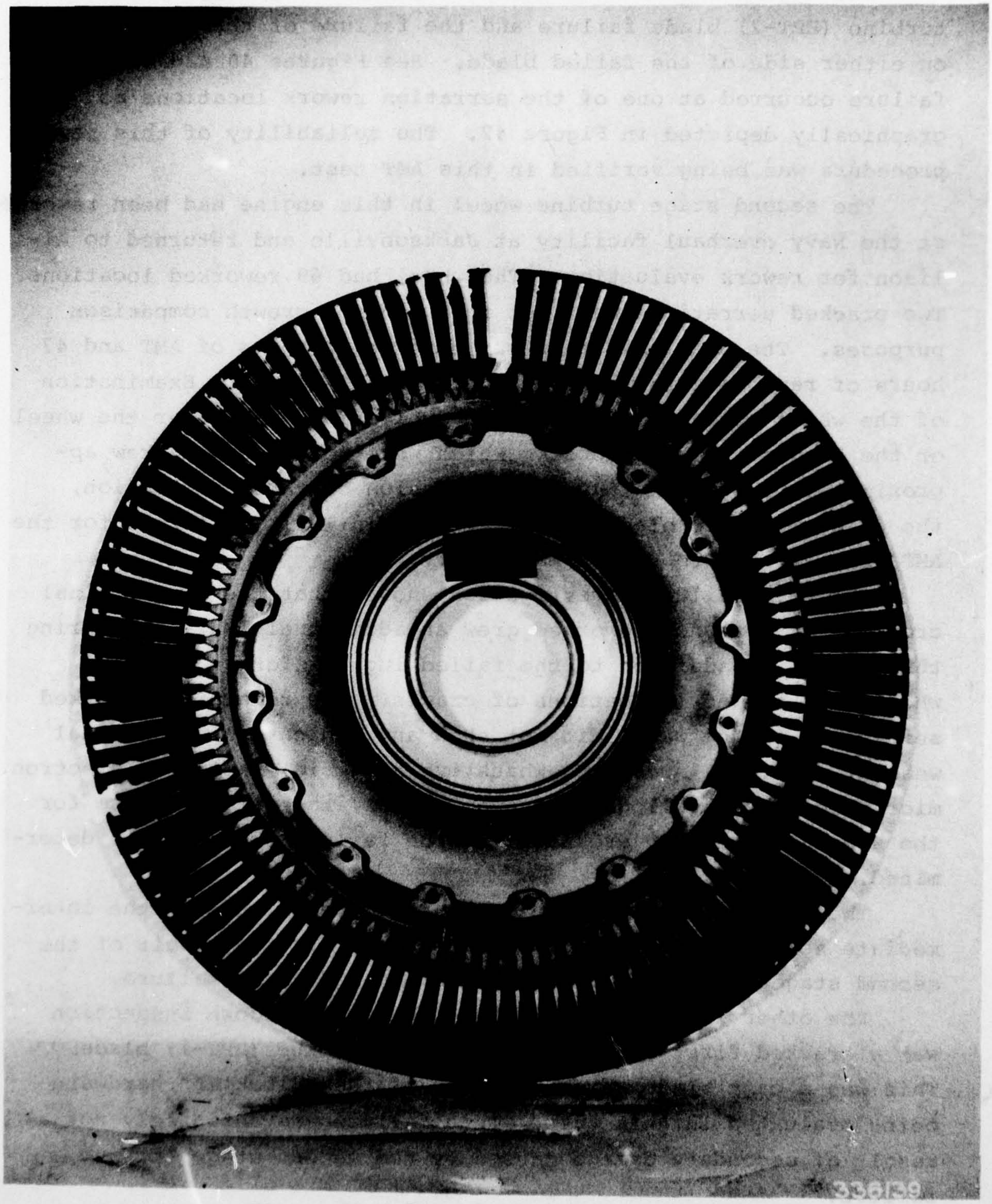


Figure 39 Second Stage H.P. Turbine

The engine failure was due to a second stage high pressure turbine (HPT-2) blade failure and the failure of the wheel lugs on either side of the failed blade. See Figures 40 and 41. The failure occurred at one of the serration rework locations as graphically depicted in Figure 42. The reliability of this rework procedure was being verified in this AMT test.

The second stage turbine wheel in this engine had been reworked at the Navy overhaul facility at Jacksonville and returned to Allison for rework evaluation. The wheel had 69 reworked locations. Two cracked serrations were not reworked for growth comparison purposes. The wheel had been run through 52 hours of AMT and 47 hours of resonance testing on an engine at Allison. Examination of the wheel revealed no new crack indications in either the wheel or the blades. The two cracks which were not reworked grew approximately 1/16 inch. At the conclusion of this examination, the wheel with new blades was installed in TF41 S/N 142163 for the AMT test at the Propulsion Laboratory.

The post failure investigation showed that the two original cracks that were not reworked grew an additional 1/32 inch during this test. In addition to the failed lug, two other reworked wheel lugs showed indications of cracks. The remaining reworked serrations on the wheel did not show any indications of unusual wear or distress. Despite exhaustive analysis, including electron microscope and metallographic examination, the primary cause for the second stage high pressure turbine failure could not be determined.

The low pressure turbine damage and the seizure of the intermediate seal on the H.P. compressor shaft were the result of the second stage high pressure turbine blade and wheel failure.

The other interesting finding from the teardown inspection was a cracked first stage high pressure turbine (HPT-1) blade. This was a cast blade which was part of the "Block 76" hardware being evaluated in this test. This failure was definitely not a result of secondary damage caused by the second stage turbine failure.

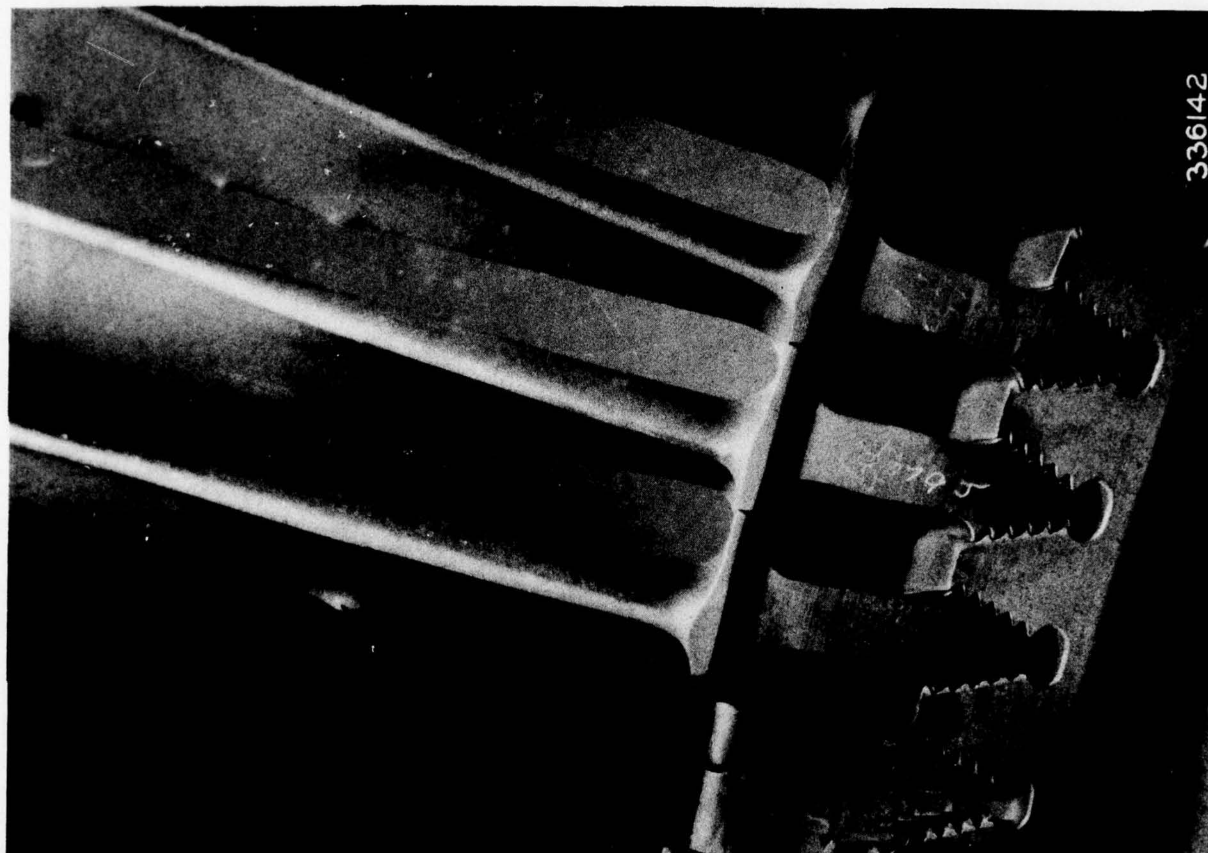


Figure 40 Failure Location - Second Stage H.P. Turbine

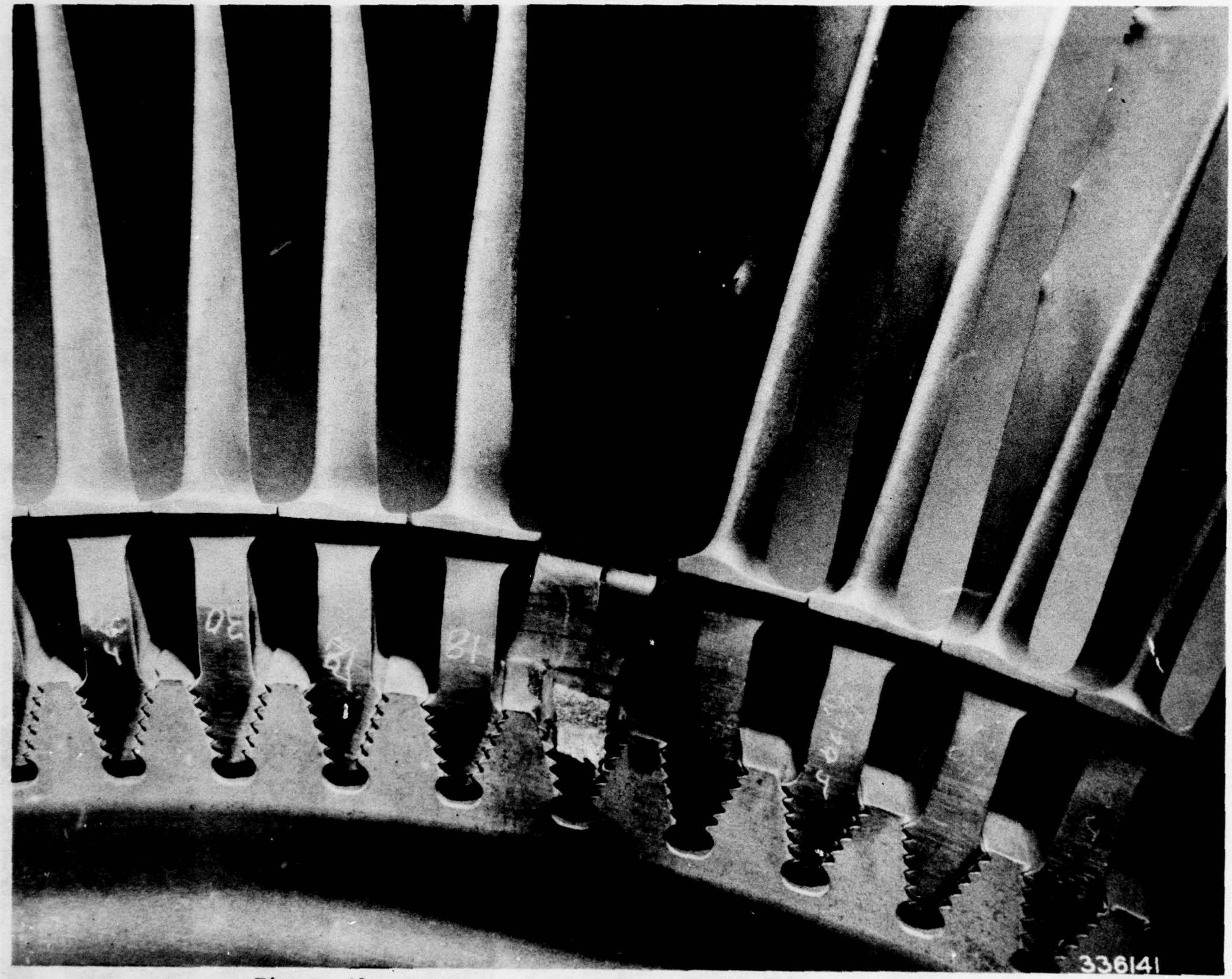


Figure 41 Failure Location with Remaining Blade Stub in Place

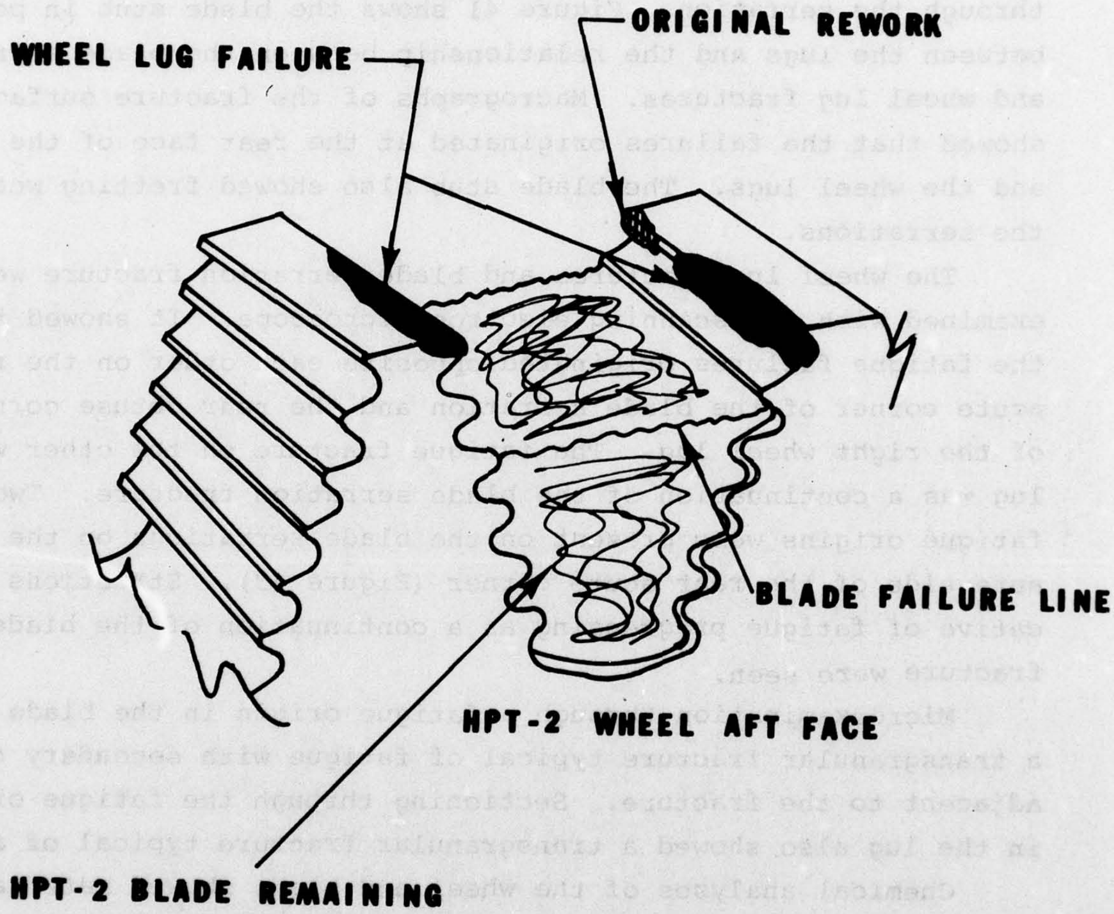


Figure 42 Schematic of Failed Wheel Lug

HPT-2 SERRATION AND LUG FAILURE ANALYSIS

A visual examination of the two adjacent wheel lugs indicated that they failed in fatigue through the top serration (Figure 40). The blade between the two lugs also failed in fatigue through the serration. Figure 41 shows the blade stub in position between the lugs and the relationship between the blade serration and wheel lug fractures. Macrographs of the fracture surfaces showed that the failures originated at the rear face of the blade and the wheel lugs. The blade stub also showed fretting wear on the serrations.

The wheel lug fractures and blade serration fracture were examined with the scanning electron microscope. It showed that the fatigue failures originated opposite each other on the rear acute corner of the blade serration and the rear obtuse corner of the right wheel lug. The fatigue fracture on the other wheel lug was a continuation of the blade serration fracture. Two fatigue origins were present on the blade serrations on the pressure side of the rear acute corner (Figure 43). Striations indicative of fatigue progressing as a continuation of the blade fracture were seen.

Microexamination through a fatigue origin in the blade showed a transgranular fracture typical of fatigue with secondary cracking adjacent to the fracture. Sectioning through the fatigue origin in the lug also showed a transgranular fracture typical of fatigue.

Chemical analyses of the wheel and blade showed material properties in conformance with the specified requirements.

ADDITIONAL HPT-2 WHEEL LUG FAILURE ANALYSIS

Examination of the wheel showed crack indications on 6 other second stage high pressure turbine wheel lugs. Two of these cracks were "reference" cracks that were left to check growth. Three of the other cracks were confirmed to be fatigue, two in the front

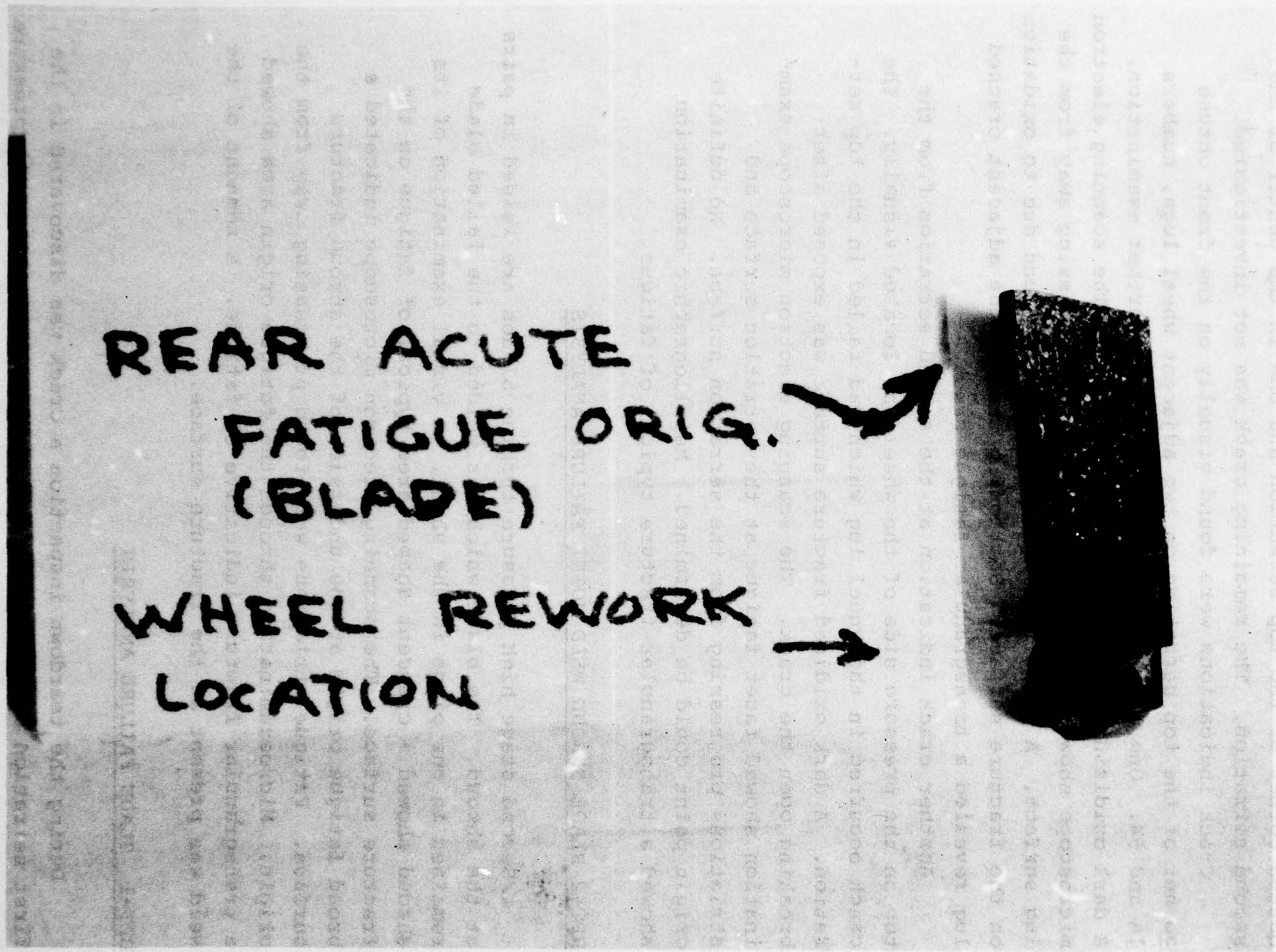


Figure 43 Failure Surface of Remaining Blade Stub

obtuse corner of the top serration and one in the center of the second serration. The remaining crack was not investigated.

Crack indications were found visually on the front obtuse corner of the top serration on two adjacent wheel lugs, numbers 1A and 54. One was opened mechanically for further examination. A dark oxidizing fracture surface was noted. The scanning electron microscope showed a broad fatigue origin progressing away from the lug surface. A definite origin could not be found due to oxidation on the fracture surface. Sectioning through the adjacent cracked lug revealed a transgranular fatigue crack.

Another crack indication at the second serration from the top on the pressure side of the wheel was located visually. The crack occurred in the wheel lug which had failed in the top serration. A dark oxidized fracture surface was exposed after breaking open the crack. The scanning electron microscope examination showed facet fatigue at the serration surface and striations progressing from the serration surface. No definite origin point could be determined. Metallographic examination showed a transgranular fracture typical of fatigue.

HPT-2 BLADE SHROUD WELD JOINT FAILURE ANALYSIS

Second stage high pressure turbine blades are welded in pairs at the shroud. The blade which was welded to the failed blade remained in one piece in the wheel. A visual examination of its shroud showed a crescent shaped area typical of fatigue on the fracture surface. The scanning electron microscope indicated a broad fatigue origin at the underside of the shroud fracture surface. Fatigue striations were found progressing away from the origin. Microexamination through the fatigue origin area showed a transgranular fracture indicative of fatigue. A remnant of the weld was present at the fracture surface.

HPT-1 BLADE FAILURE ANALYSIS

During the teardown inspection a crack was discovered in the first serration on the pressure side of a first stage high pressure

turbine blade in the number 57 position. Scanning electron microscope examination of the failure surface showed flat fracture areas and striations indicative of fatigue. Photomicrographs showed a partially transgranular primary failure and transgranular secondary crack indicative of fatigue originating in the coating on the serration surface. Coatings of varied thickness were found on other serrations on the pressure side of the dovetail. No coating was found on the suction side of the failed dovetail.

Nine other first stage high pressure turbine blades without any crack indication were destructively examined to determine the depth of thermal fatigue cracks at internal post locations. These blades compared very favorably with other AMT tested standard production blades.

All the other teardown findings were considered to be normal wear for 106 AMT hours or secondary damage caused by the engine failure. Therefore, they were not metallurgically analyzed in great detail.

IX. SUMMARY AND CONCLUSIONS

An accelerated mission test of a TF41-A-1 engine S/N 142163 was run at the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility. The objectives of this test were to establish the durability of a set of hardware modifications known as "Block 76" hardware, to verify the reliability of a second stage high pressure turbine wheel repair scheme for clearance to 450 hours of service life, and to track and document the overall engine performance deterioration under realistic usage conditions. The test was initially scheduled for 263 hours but was prematurely terminated after 106 AMT hours (144 total engine operating hours) due to a failure in the second stage high pressure turbine.

The engine was returned to Allison for a teardown inspection. Metallurgical examination showed a second stage high pressure turbine blade failed in fatigue which originated at the rear acute corner in the root of the second serration. The wheel lugs on either side of the failed blade also failed in fatigue as well as the shroud weld joint attaching the failed blade to its adjoining blade. The failure was located at a wheel lug which has been reworked. Four additional crack indications (besides the two "reference" cracks) were found in this wheel, three of which were confirmed as fatigue failures. Two of the indications were found on other lugs that had also been reworked. The primary cause for the second stage failure could not be determined. However, as a result of this test and subsequent failure, the rework maximum service life was <u>not</u> extended to 450 hours, but remained at 250 hours. In addition, five reworked wheels, with approximately 225 service hours each were identified in the Navy fleet and were recalled to Allison for further investigation (see Appendix D).

In general, the "Block 76" hardware performed very well and was not a factor in the engine's failure. One cast first stage high pressure turbine blade did however, have crack indications. Metallurgical examination showed a fatigue crack originating in the coating in the bottom serration on the pressure side. Analysis

indicated that the coating was of varied thickness in each serration which caused an uneven blade loading resulting in the crack. Nine additional cast blades were destructively tested and they compared favorably with standard production blades after similar AMT testing.

The other items noted in the teardown inspection report were either considered normal wear and tear or are secondary damage caused by the second stage turbine failure and are not areas of major concern.

Deterioration effects were difficult to quantify because of the minimum amount of data due to the reduced test time. This was compounded by the lack of consistency in what data was available due to varying inlet temperature, bleed flow, and trim. Comparing the performance calibrations at 0 and 100 AMT test hours indicates that on operation on the mass flow limiter the deteriorated engine produced <u>more</u> thrust. In this case there was about a 1% increase in thrust but at the expense of nearly a 4% increase in fuel flow.

The original plan for testing the "Block 76" hardware included two 263 hour AMT tests separated by a teardown and overhaul. Despite the considerable damage to the turbine section, the engine will be rebuilt and returned to "D"-Bay for continued AMT testing of the "Block 76" hardware.

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BUILD 1 OF AN ACCELERATED MISSION TEST OF A TF41 WITH BLOCK 76 --ETC(U)
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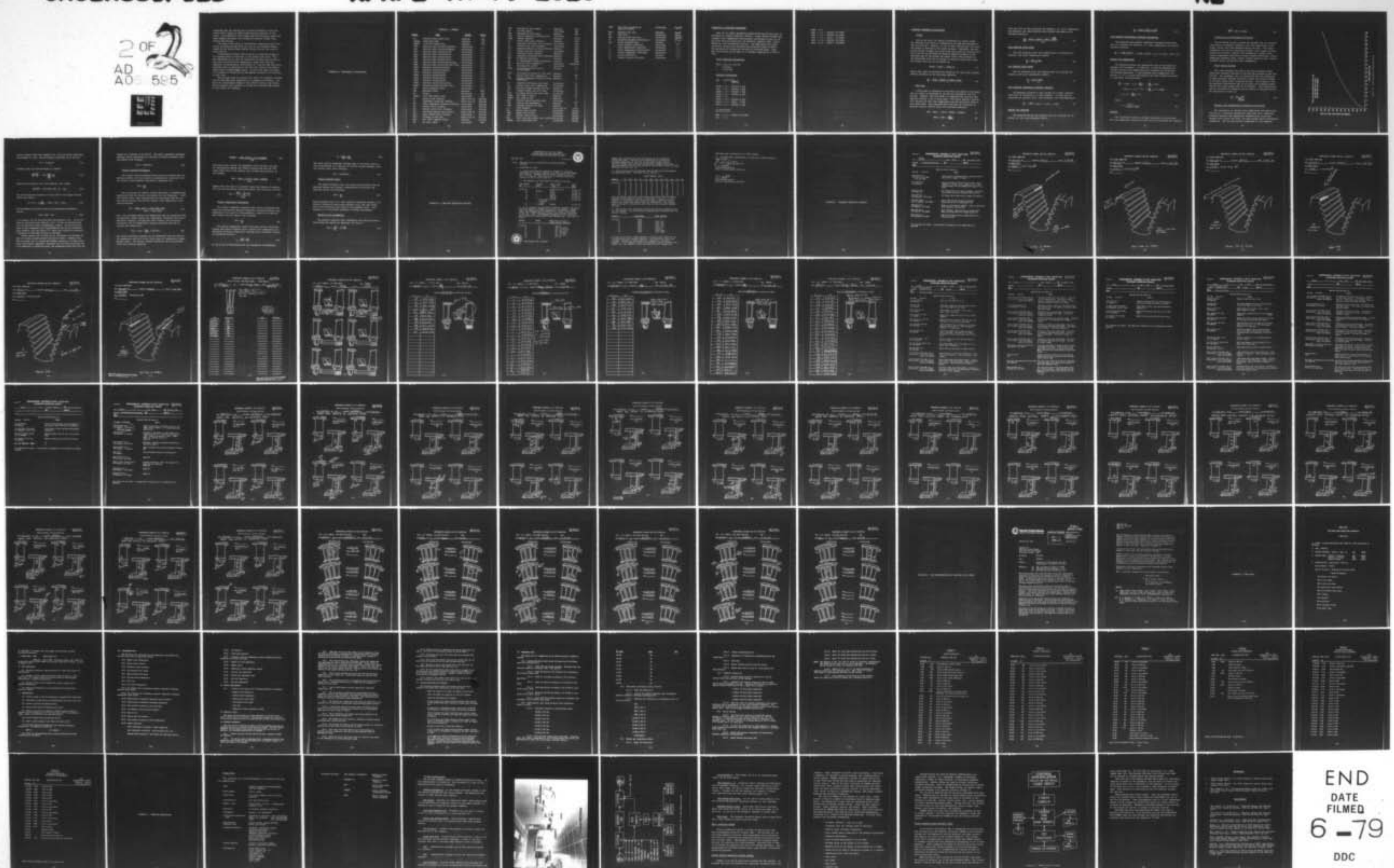

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APPENDIX A PERFORMANCE CALCULATIONS

APPENDIX A SYMBOLS

SYMBOL	NAME	SOURCE	UNITS
A4	Turbine inlet nozzle area	Constant	IN^2
ABLEED	Bleed port area	Constant	IN^2
ASCRN	Inlet FOD screen area	Constant	IN^2
CPFG	Specific heat correction/thrust	Calculated	—
CPN	Specifid heat correction/speed	Calculated	—
CPP3	Specific heat correction/P3	Calculated	—
CPP5	Specific heat correction/P5	Calculated	—
CPT3	Specific heat correction/T3	Calculated	—
CPT5	Specific heat correction/T5	Calculated	—
CPWA	Specifid heat correction/airflow	Calculated	—
CPWF	Specific heat correction/fuel flow	Calculated	—
CVPFG	Humidity correction/thrust	Calculated	—
CVPN	Humidity correction/speed	Calculated	—
CVPP3	Humidity correction/P3	Calculated	—
CVPP5	Humidity correction/P5	Calculated	—
CVPT3	Humidity correction/T3	Calculated	—
CVPT5	Humidity correction/T5	Calculated	—
CVPWA	Humidity correction/airflow	Calculated	—
CVPWF	Humidity correction/fuel flow	Calculated	—
EPR	Engine pressure ratio	Calcualted	—
FGM	Measured thrust	Measured	LB_F
FG	Thrust	Calculated	LB_F
FSCRN	Inlet FOD screen force	Calculated	LB_F
H1	Engine inlet enthalpy	Table Look Up	BTU/LB_M
H3	Compressor discharge enthalpy	Table Look Up	BTU/LB_M
H3I	Ideal compressor discharge enthalpy	Calculated	BTU/LB_M
H4	Turbine inlet enthalpy	Calculated	BTU/LB_M
H41	Turbine rotor inlet enthalpy	Calculated	BTU/LB_M
H5	Untrimmed exhaust gas enthalpy	Table Look Up	BTU/LB_M
H5I	Ideal turbine exit enthalpy	Calculated	BTU/LB_M
HF4	enthalpy of the fuel	Table Look Up	BTU/LB_M
LHV	Fuel lower heating value	Constant	BTU/LB_M
NH	HP rotor speed	Calculated	RPM

NHM	Measured HP rotor speed	Measured	RPM
NL	LP rotor speed	Calculated	RPM
NLM	Measured LP rotor speed	Measured	RPM
OPR	Overall compressor pressure ratio	Calculated	___
PAMB	Ambient pressure	Measured	IN HG
P1	Engine inlet total pressure	Measured	PSIA
P3	Compressor discharge total pressure	Calculated	PSIA
P4	Turbine inlet total pressure	Calculated	PSIA
P5M	Measured exhaust gas total pressure	Measured	PSIG
P5	Exhaust gas total pressure	Calculated	PSIA
PS1	Bellmouth static pressure	Measured	PSIA
PS3	Compressor discharge static pressure	Measured	PSIG
RES	T5 Ballast resistance	Constant	OHMS
RH	T5 thermocouple harness resistance	Constant	OHMS
SFC	Specific fuel consumption	Calculated	$LB_M/HR/LB_F$
SGF	Fuel specific gravity	Calculated	___
SGFM	Calibrated specific gravity of flow meter	Constant	___
SGFT	Fuel specific gravity at fuel tank	Measured	___
T1	Engine inlet total temperature	Measured	^oF
T3M	Measured compressor discharge total temperature	Measured	^oF
T3	Compressor discharge total temp.	Calculated	^oF
T4	Turbine inlet total temperature	Calculated	^oR
T5M	Measured trimmed exhaust gas temp	Measured	^oF
T5	Trimmed exhaust gas total temp	Calculated	^oF
T5UT	Untrimmed exhaust gas total temp	Calculated	^oF
TFUEL	Fuel temp at engine	Measured	^oF
TFUELT	Fuel temp at tank	Measured	^oF
TPR	Overall turbine pressure ratio	Calculated	___
TJB	Junction box temperature	Measured	^oF
TJBS	Standard junction box temp	Constant	^oF
V_P	Vapor pressure	Table Look Up	IN HG
WA	Engine inlet airflow	Calculated	LB_M/SEC
WA22	Engine core airflow	Calculated	LB_M/SEC
WA4	Turbine inlet airflow	Calculated	LB_M/SEC
WAI	Total corrected engine inlet airflow	Calculated	LB_M/SEC
WBLEED	11th stage bleed flow	Calculated	LB_M/SEC

WFCS	Fuel flow corrected for specific gravity	Calculated	LB_M/SEC
WFM	Measured fuel flow	Measured	LB_M/HR
WF	Fuel flow	Calculated	LB_M/HR
WG4	Turbine inlet gas flow	Calculated	LB_M/SEC
ΔP	Bellmouth pressure differential	Calculated	IN H_2O
ΔP_B	Burner pressure drop	Constant	___
δ	Inlet pressure correction	Calculated	___
θ	Inlet temperature correction	Calculated	___
θ^*	Inlet temperature correction/T5	Calculated	___
η_C	Overall compressor efficiency	Calculated	___
η_B	Burner efficiency	Constant	___
η_T	Overall turbine efficiency	Calculated	___

CORRECTION OF MEASURED PARAMETERS

Most of the engine parameters measured during the test must be corrected for several different effects. These effects include the standard inlet temperature and pressure corrections as well as empirically derived corrections for humidity, specific heat, instrumentation, and installation effects. The expressions for these correction factors were obtained from Technical Order 2J-TF41-3. The procedure for correcting the data is outlined below. Note that corrections can be made for a standard temperature of 59^{o}F or 77^{o}F.

Inlet Condition Corrections

TSTD = 518.7 or 536.7°R

θ = T1/TSTD

δ = P1/14.696

Humidity Corrections

$$HUM = 4353.2\left(\frac{V_P}{PAMB-V_P}\right)$$

CVPFG = 1.0 + .0000143 x HUM

CVPN = 1.0 - .0000343 x HUM

CVPWA = 1.0 + .0000457 x HUM

CVPWF = 1.0 - .0000814 x HUM

CVPP3 = 1.0

CVPP5 = 1.0 + .0000079 x HUM

CVPT3 = 1.0 + .00003 x HUM

CVPT5 = 1.0 - .0000264 x HUM

C_P Corrections

CPFG = 1.0 - .0001214 (T1-TSTD)

CPN = 1.0

CPWA = 1.0

CPWF = 1.0 - .0003846 (T1-TSTD)

CPP3 = 1.0 - .0000645 (T1-TSTD)

CPP5 = 1.0 - .000071 (T1-TSTD)

CPT3 = 1.0 + .0001355 (T1-TSTD)

CPT5 = 1.0 - .000071 (T1-TSTD)

CORRECTED PARAMETER CALCULATIONS

Thrust

During the test, the engine is mounted on a thrust stand. The measured scale force is displayed on the CRT and recorded on the line printer. However, in the "D"-Bay installation, the inlet FOD screen is mounted on the thrust balance. Therefore, the displayed thrust includes the screen drag which must be accounted for. This loss can be estimated by assuming ambient pressure on the upstream side of the screen and engine inlet total pressure on the downstream side with no change in velocity across the screen. The screen force can be calculated as:

$$FSCRN = ASCRN \times (PAMB-P1) \quad (1)$$

Thrust must also be corrected for humidity, CP, and inlet pressure effects according to the following equation:

$$\frac{FG}{\delta} = \frac{(FGM + FSCRN) \times CVPFG \times CPFG}{\delta} \quad (2)$$

Fuel Flow

A flow meter is installed in the fuel line ahead of the engine and its output is displayed on the CRT and recorded on the line printer. However, the flow meter is calibrated for only one fuel specific gravity (.762 in this case). The actual specific gravity is a function of both fuel temperature and the particular batch of fuel being used. The displayed fuel flow must be corrected for specific gravity effects using the following equations:

$$SGF = SGFT - .0004 \times (TFUEL - TFUELT) \quad (3)$$

$$WFCS = WFM \times \left(\frac{SGF}{SGFM}\right) \quad (4)$$

This fuel flow is then corrected for humidity, CP, inlet temperature and pressure, and lower heating value effects according to the following equation:

$$\frac{WF}{\sqrt{\theta\delta}} = \frac{WFCS \times CVPWF \times CPWF \times \frac{LHV}{18400}}{\delta\sqrt{\theta}} \qquad (5)$$

HIGH PRESSURE ROTOR SPEED

The high pressure rotor tach reading must be corrected for humidity, and inlet temperature effects.

$$\frac{NH}{\sqrt{\theta}} = \frac{NHM \times CVPN}{\sqrt{\theta}} \qquad (6)$$

LOW PRESSURE ROTOR SPEED

The low pressure rotor tach reading must be corrected for humidity, and inlet temperature effects.

$$\frac{NL}{\sqrt{\theta}} = \frac{NLM \times CVPN}{\sqrt{\theta}} \qquad (7)$$

HIGH PRESSURE COMPRESSOR DISCHARGE PRESSURE

The measured variable at this station is a static pressure which must be converted to a total pressure. It must also be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P3}{\delta} = \{(\frac{PS3}{\delta} \times CPP3) + 4.56\} \times 1.0512 \qquad (8)$$

EXHAUST GAS PRESSURE

The measured exhaust gas pressure must be corrected for humidity, CP, and inlet pressure effects.

$$\frac{P5}{\delta} = \frac{P5M \times CVPP5 \times CPP5}{\delta} \quad (9)$$

HIGH PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

The measured high pressure compressor discharge temperature must be corrected for humidity, CP, inlet temperature, and instrumentation effects.

$$\frac{T3}{\theta} = \{(\frac{T3M + 459.7}{\theta} \times CVPT3 \times CPT3) + 1.2\} \times 1.003 - 459.7 \quad (10)$$

EXHAUST GAS TEMPERATURE

The measured exhaust gas temperature must be corrected for humidity and CP effects. In addition, it must be adjusted to a standard junction box temperature and corrected for the ballast and harness resistance. A non-standard inlet temperature correction ($\theta^{.8788}$) is also used because TF41 past history has shown it correlates the data better.

$$\frac{T5}{\theta^*} = (\{T5m \times (1.0 + \frac{RH}{RES})\} - (\frac{RH}{RES} \times TJB)$$

$$+ (\{459.7 \times (1.0 - \theta^*)\} + \{\frac{RH}{RES} \times \theta^* \times TJBS\})$$

$$\div (\{1.0 + \frac{RH}{RES}\} \times \theta^* \quad (11)$$

where;

$$\theta^* = \frac{\theta^{.8788}}{CVPT5 \times CPT5} \quad (12)$$

AIRFLOW

The calculated airflow is already corrected for inlet pressure and temperature effects but must still be corrected for humidity.

$$\frac{WA\sqrt{\theta}}{\delta} = WAI \times CVPWA \qquad (13)$$

Calculations of Performance Variables

The following section presents the methods used to calculate some engine performance parameters from the temperatures, pressures, forces, and flows measured during the test. The engine parameters that can be calculated include: total engine airflow, engine core airflow, turbine inlet temperature, bypass ratio, overall compressor efficiency, overall turbine efficiency, overall compressor pressure ratio, overall turbine pressure ratio, engine pressure ratio, and specific fuel consumption.

Total Engine Airflow

The inlet bellmouth has static and total pressure probes which have readings displayed on the CRT and recorded on the line printer. The parameter, $\Delta P/\delta$ is calculated from the difference in these pressure readings and used to enter the curve in Figure 44 to yield engine total corrected airflow. (This curve is from the bellmouth manufacturer and is only good for bellmouth number 6872762 and screen number 6872166 or 6798364). This airflow must then be corrected for humidity and Cp effects as outlined earlier. The calculation of $\Delta P/\delta$ is:

$$\frac{\Delta P}{\delta} = \frac{P1 - PS1}{\frac{P1}{14.696}} \qquad (14)$$

Turbine Inlet Temperature and Engine Core Airflow

The calculation of turbine inlet temperature and engine core airflow is an iterative calculation using fuel flow, compressor discharge pressure and temperature (appropriately corrected), turbine inlet nozzle flow area, and some assumed burner performance parameters. For the calculations summarized in this appendix,

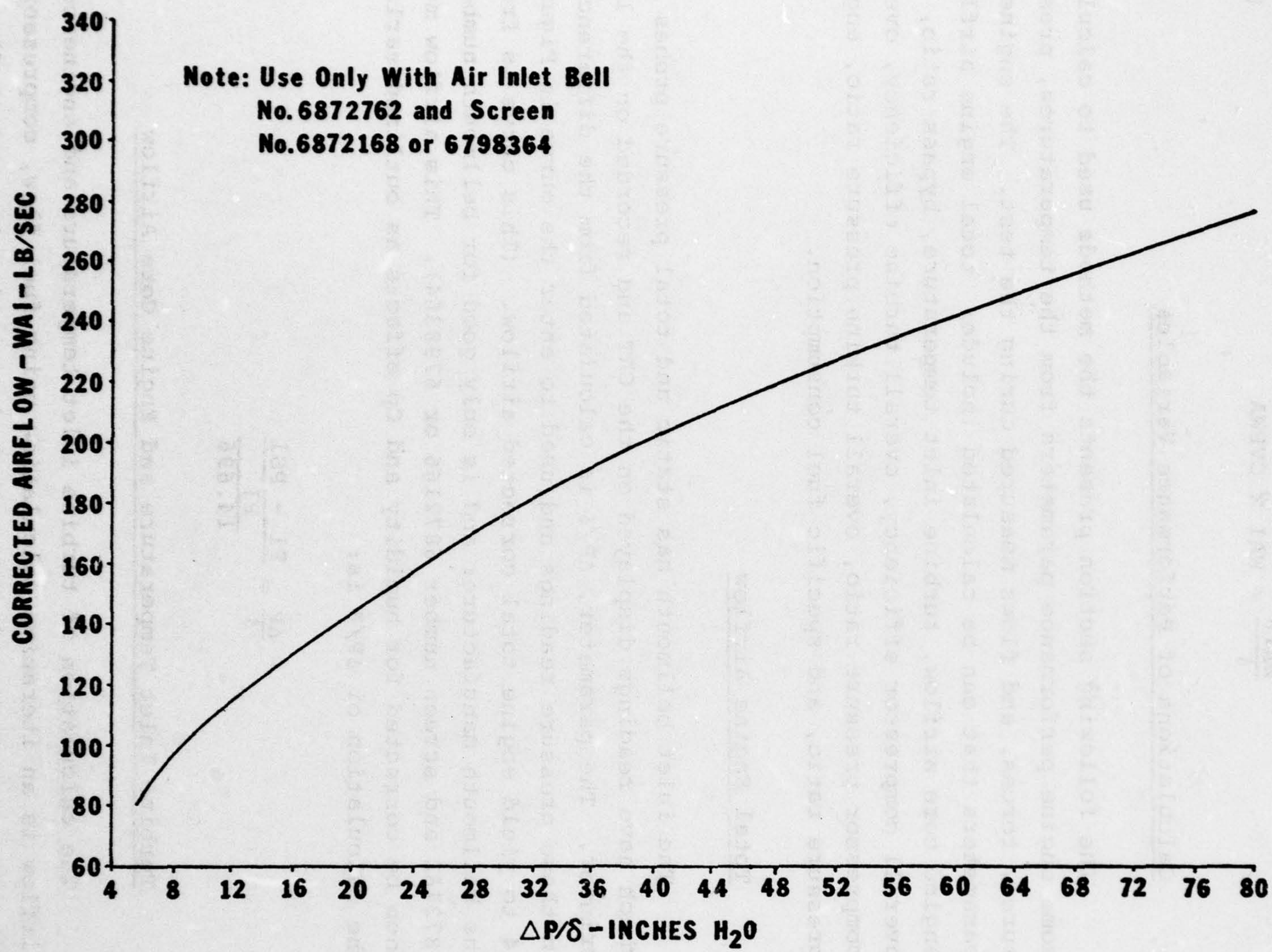


Figure 44 Inlet Bellmouth Characteristics

burner pressure drop was assumed to be .055 and burner efficiency was assumed at .999. The calculation procedure is as follows:

$$P4 = (1-\Delta P_B)P3 \tag{15}$$

Assuming that the turbine nozzle is choked:

$$\frac{WG4\sqrt{T4}}{P4 \quad A4} = .5312 \; \frac{\frac{LBm}{SEC}\sqrt{\sigma_R}}{LB_F} \tag{16}$$

Substituting equation (15) into equation (16) yields:

$$WG4\sqrt{T4} = .5312(A4) \; (P3) \; (1 - \Delta P_B) \tag{17}$$

The other governing equation in this case is the energy balance across the burner:

$$H4 = H3 + \eta_B(\frac{WF}{WA4}) \quad (LHV + 182. - HF4) \tag{18}$$

The procedure for solving these two simultaneous equations, noting:

$$WA4 = WG4 - WF \tag{19}$$

is to guess a T4 and calculate WG4 from equation (17). An H4 can then be calculated from equation (18). T4 can be obtained from the calculated H4 using thermodynamic tables. The entire procedure is then repeated until the guessed T4 and the T4 calculated from equation (18) are within 1^{o}. When this iteration converges, a solution is obtained for both T4 and WA4.

Before engine core airflow can be calculated, an estimate of the 11th stage customer bleed flow must be made. Assuming that the discharge port is choked and further assuming a 5% total pressure loss between compressor discharge and the bleed discharge and a 5% reduction in effective area, the estimated bleed flow rate is:

tables as a function of T1 and T3. The ideal compressor discharge enthalpy can be calculated as a function of overall pressure ratio and engine inlet enthalpy.

$$H3I = f(OPR, H1) \tag{25}$$

<u>Overall Turbine Performance</u>

The overall turbine pressure ratio can be calculated from the measured exhaust gas total pressure (appropriately corrected) and the turbine inlet pressure calculated in equation (15).

$$TPR = \frac{P4}{P5}$$

The calculation of overall turbine efficiency is somewhat more complicated than the similar calculation for the compressor. First the turbine rotor inlet enthalpy must be calculated from the turbine nozzle cooling flow and the turbine inlet temperature calculated previously.

$$H41 = \frac{(WG4)\ (H4) + .0318\ (WA4)\ (H3)}{WG4 + .0318\ (WA4)} \tag{27}$$

Next, the untrimmed exhaust gas temperature must be calculated from the measured trimmed exhaust gas temperature (corrected for instrumentation, humidity, and specific heat effects) the T5 ballast resistance, the T5 thermocouple harness resistance and the T5 junction box temperature.

$$T5UT = T5M + \left(\frac{RH}{RES}\right)\ (T5M-TJB) \tag{28}$$

The turbine discharge enthalpy can be determined from the calculated temperature and fuel to air ratio using the appropriate thermodynamic table. The overall turbine efficiency can be calculated using the following equation.

$$\text{WBLEED} = \frac{.532(.95\text{xP3})\ (.95 \times \text{ABLEED})}{\sqrt{\text{T3}}} \tag{20}$$

The engine core airflow (IP compressor inlet airflow) can then be calculated by adding the turbine cooling flow and the 11th stage bleed flow to the turbine inlet airflow and allowing .2% for leakage.

$$\text{WA22} = \frac{\text{WA4} + (.0604 \times \text{WA4}) + \text{WBLEED}}{.998} \tag{21}$$

Bypass ratio can then be calculated using the results of equation (21) and the previously calculated engine total corrected airflow.

$$\text{BPR} = \frac{\frac{\text{WA}\sqrt{\theta}}{\delta}\ \left(\frac{\delta}{\sqrt{\theta}}\right) - \text{WA22}}{\text{WA22}} \tag{22}$$

Overall Compressor Performance

The overall compressor pressure ratio can be calculated very simply by dividing the measured compressor discharge pressure (appropriately corrected for instrumentation, humidity and specific heat effects) by the engine inlet pressure.

$$\text{OPR} = \frac{\text{P3}}{\text{P1}} \tag{23}$$

The overall compression system efficiency can be calculated, knowing the overall pressure ratio, engine inlet temperature and compressor discharge temperature (appropriately corrected) through the following equation:

$$\eta_C = \frac{\text{H3I} - \text{H1}}{\text{H3} - \text{H1}} \tag{24}$$

H1 and H3 can be determined from the appropriate thermodynamic

$$\eta_T = \frac{H4I - H5}{H41 - H51} \qquad (29)$$

The ideal turbine discharge enthalpy used in the above equation can be calculated as a function of overall turbine pressure ratio and turbine rotor inlet enthalpy.

$$H5I = f(TPR, H41) \qquad (30)$$

Engine Pressure Ratio

The engine pressure ratio can easily be calculated from the measured exhaust gas pressure (appropriately corrected) and measured engine inlet pressure.

$$EPR = \frac{P5}{PI} \qquad (31)$$

Engine pressure ratio is a very important parameter because it is directly related to both nozzle pressure ratio and thus thrust and is also generally very close to fan pressure ratio. This parameter is an excellent indicator of engine performance.

Specific Fuel Consumption

The engine's specific fuel consumption can easily be calculated using the results of equations (2) and (5).

$$SFC = \left(\frac{WF}{\sqrt{\theta}\delta}\right) \quad \sqrt{\theta}/\left(\frac{FG}{\delta}\right) \qquad (32)$$

APPENDIX B LUBRICANT MONITORING REPORTS

DEPARTMENT OF THE AIR FORCE
AIR FORCE AERO PROPULSION LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: SFL 16 Jun 78

SUBJECT: Analysis of Test Stand TF-41 Lubricant Samples (OP-103)

TO: AFAPL/TBA (R. May)

1. This letter report contains a summary of analyses performed on lubricant samples from test stand TF41 engine (S/N 142163). Samples were received during the period Oct 77 to Jan 78. This letter is to confirm reports by telecon 23 Jan 77 and 18 Jan 78.

2. The samples are identified and coded as follows:

LAB SAMPLE NO	ENGINE S/N	TOTAL TIME (hr)	DATE RECD
OP-103-1	-	0-69-2 New Oil	21 Oct 77
-2	142163	26:17	2 Dec 77
-3	"	51:54	13 Dec 77
-4	"	76:06	19 Dec 77
-5	"	103:59	23 Dec 77
-6	"	135:00	6 Jan 78
-7	" (oil tank) (turbine fail)	143:44	16 Jan 78
-8	" filter	143:44	16 Jan 78

3. As an estimate of lubricant condition, Complete Oil Breakdown Rate Analyzer (COBRA) values were determined. Higher values on COBRA indicate degradation. On the 0-200 COBRA scale, MIL-L-7808 lubricant values >100 indicate stressing of the oil. Also, the foaming tendencies of the lubricant were determined using Federal Test Method 3213. Data are as follow:

SAMPLE	COBRA	FOAM (ml @ 30 min) (1000 cc/min airflow)
OP-103-1	3	15 ml
-2	14	OF* (15 min)
-3	16	OF (12.5 min)
-4	12	OF (23 sec)
-5	18	OF (19 min)
-6	11	OF (5 min)
-7	11	235 ml
-8	15	-

*overfoamed test cylinder

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

COBRA data indicate that the lubricant was not stressed during the runs. The foam test indicates an increase in foaming tendencies of the oil on use which often occurs. The foam values also indicate significant changes occurring between samples OP-103-4 and OP-103-5, which may be due to large additions of new oil, etc.

4. Trace metals were determined with an emission spectrometer (Rickenbacker AFB). The data are as follow:

TRACE METALS (ppm)

SAMPLE	Fe	Ag	Al	Cr	Cu	Mg	Ni	Pb	Si	Sn	Ti	Mo
OP-103-1	1	0	0	0	0	0	0	0	5	11	1	1
-2	5	0	0	0	5	0	0	0	22	7	1	1
-3	3	0	0	0	4	0	0	0	16	8	1	1
-4	3	0	0	0	3	0	0	0	13	9	1	1
-5	2	0	2	0	0	8	0	0	9	6	1	1
-6	1	0	0	0	2	1	0	0	6	7	0	1
-7	10	1	0	1	2	10	0	0	10	8	0	1
-8	9	7	0	1	4	9	0	0	11	11	0	1

Silicon values which have often been associated with lubricant foaming follow general trends in foam data. Silicon in TF41 engines is frequently from silicones used in engine build-up. Values for other wear metals are not unexpected. The sudden jump in Mg may be associated with wear in the external gearbox housing.

5. Wear debris was separated and microscopically examined with the ferrograph. The following ferrograms were prepared with the overall rating:

SAMPLE	FERROGRAM	WEAR RATING
OP-103-1	2379	-
-2	2380	Very low
-3	1650	Very low
-4	4952	Very low
-5	4975	Very low
-6	4953	Normal
-7	4956	Very high
-8	4957	Very high

As seen in the data, large amounts of debris were found in the oil only after the turbine failure. For OP-103-6, there was a slight increase in wear debris as compared to previous samples. A few fatigue chunks and fatigue related spheres were found, but the number of such particles did not suggest an

abnormal wear situation for a TF41 engine.

6. If additional information is required, please contact this office.

P W Centers

P. W. CENTERS
Lubrication Branch
Fuels & Lubrication Division

H. A. Smith

H. A. SMITH
Lubrication Branch
Fuels & Lubrication Division

3

APPENDIX C TEARDOWN INSPECTION REPORTS

FORM 1010187 (7/71)

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 ~~142136~~ T.D. 1 MODEL TF41 T.D. DATE 24 January 1978

INSPECTORS Fisher/Nicely/Seidel TOTAL TIME ______ ENDURANCE TIME ______

dl
REASON FOR T.D. ______

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Wheel-HPT Stg 2 P/N 6861135, S/N 2894 Asm S/N 10198	Zyglo results indicated several cracked serrations as charted on pages 2 through 7.
Blade-HPT Stg 2 P/N 6869079J	Zyglo of serration area of 54 pairs and 1 single piece OK; 7 blades listed on page 8 with a crack between blades, but are damaged and rubbed in this area.
Blade-LPT Stg 1 P/N 6865616-R	All blade airfoils are heavily damaged. Serrations were cleaned and Zyglo inspected, and found OK.
Blade-HPT Stg 1 P/N 6894240A - 100 pieces	For Zyglo results see charts on pages 9 through 14.
Wheel-HPT Stg 1 Asm P/N 6894579, S/N 12583	Shaft, seal and driving dowels attached. Serrations and drive flange Zyglo'd OK.
Blade-LPT Stg 1 P/N 6864002 - 79 pieces	Blade air foils heavily damaged. Zyglo of serrations only revealed no indications.
Wheel-LPT Stg 2 P/N 6865722, S/N 488GAC	Shaft attached. Bearing stack up on Rear Shaft. Wheel serrations and drive flange Zyglo'd OK.
Wheel-LPT Stg 1 P/N 6867689, S/N 186GV	Zyglo with sleeve and drive flange dowels still installed was OK.

This completes the report. Any additional information will be submitted as an addendum.

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

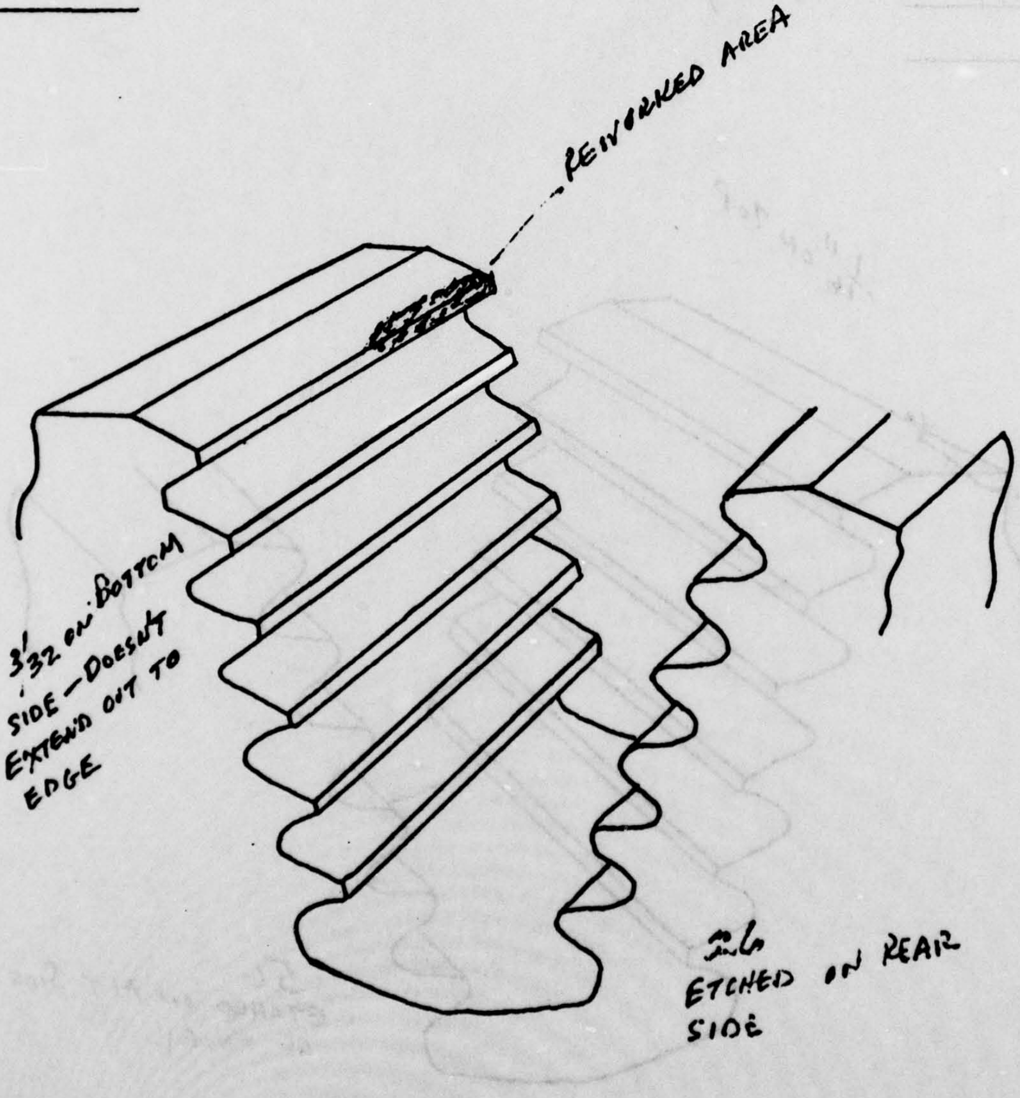
TF41 BLADE SERRATIONS

Unit 142163 TD________ Inspector NICELY ____________ Date 1-24-78

P/N 686 1135

S/N 2894 - 10198 Assy S/N

Pos.__________



..NT SIDE OF WHEEL

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

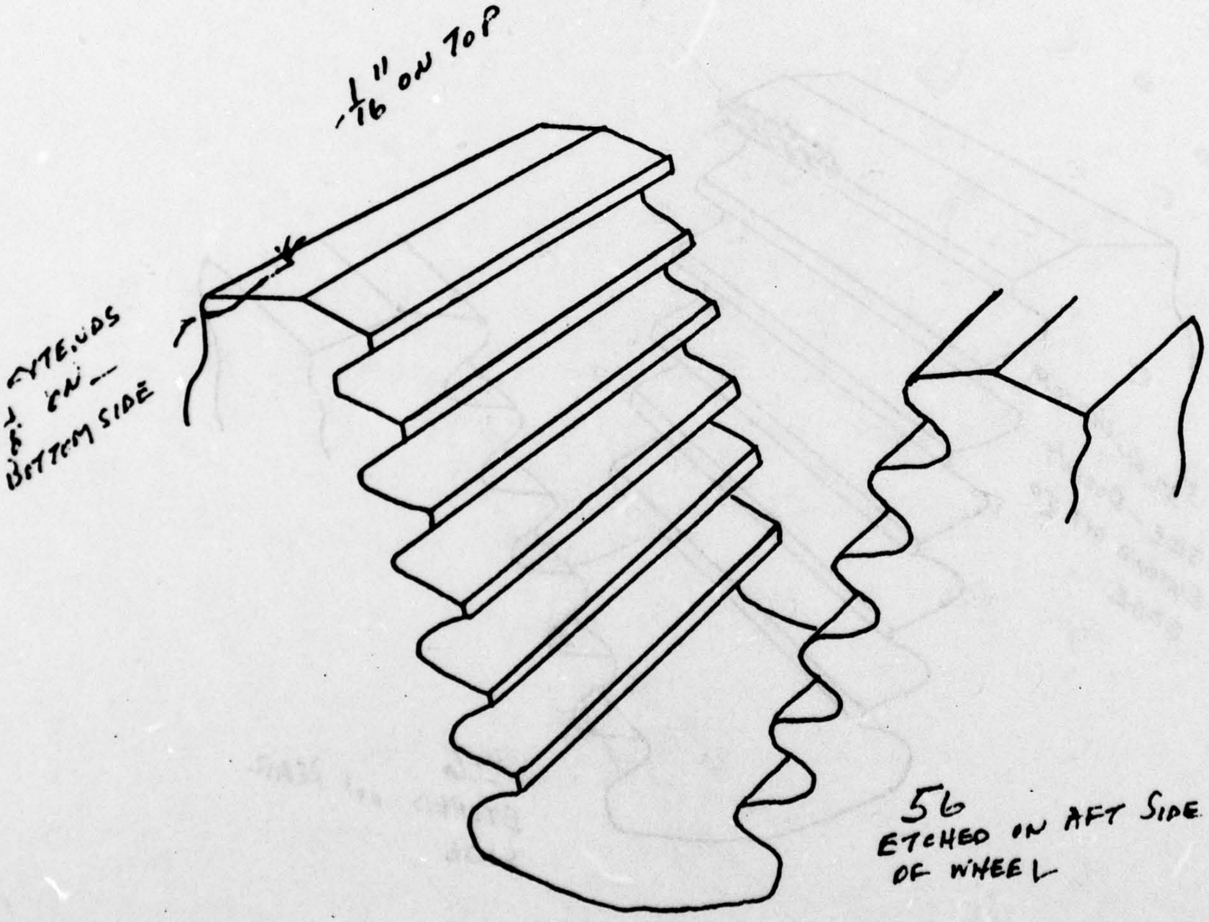
TF41 BLADE SERRATIONS

Unit 142163 TD________ Inspector NICELY Date 1-24-76

P/N 6861135

S/N 2594 — 10198 Assy S/N

Pos.________



FRONT SIDE OF WHEEL

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

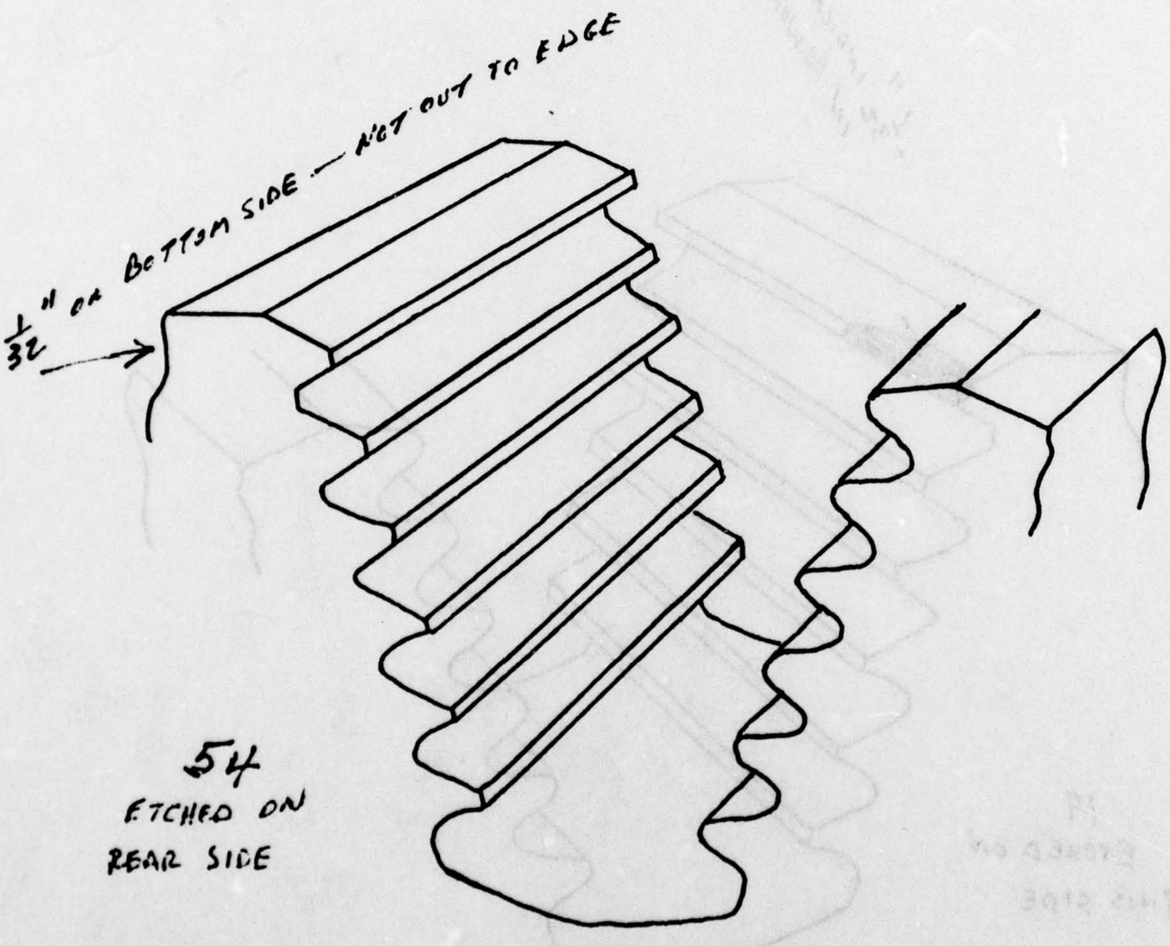
TF41 BLADE SERRATIONS

Unit 142163 TD________ Inspector NICELY Date 1-24-78

P/N 6861135

S/N 2894 - 10198 Assy S/N

Pos.__________



FRONT SIDE OF WHEEL

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

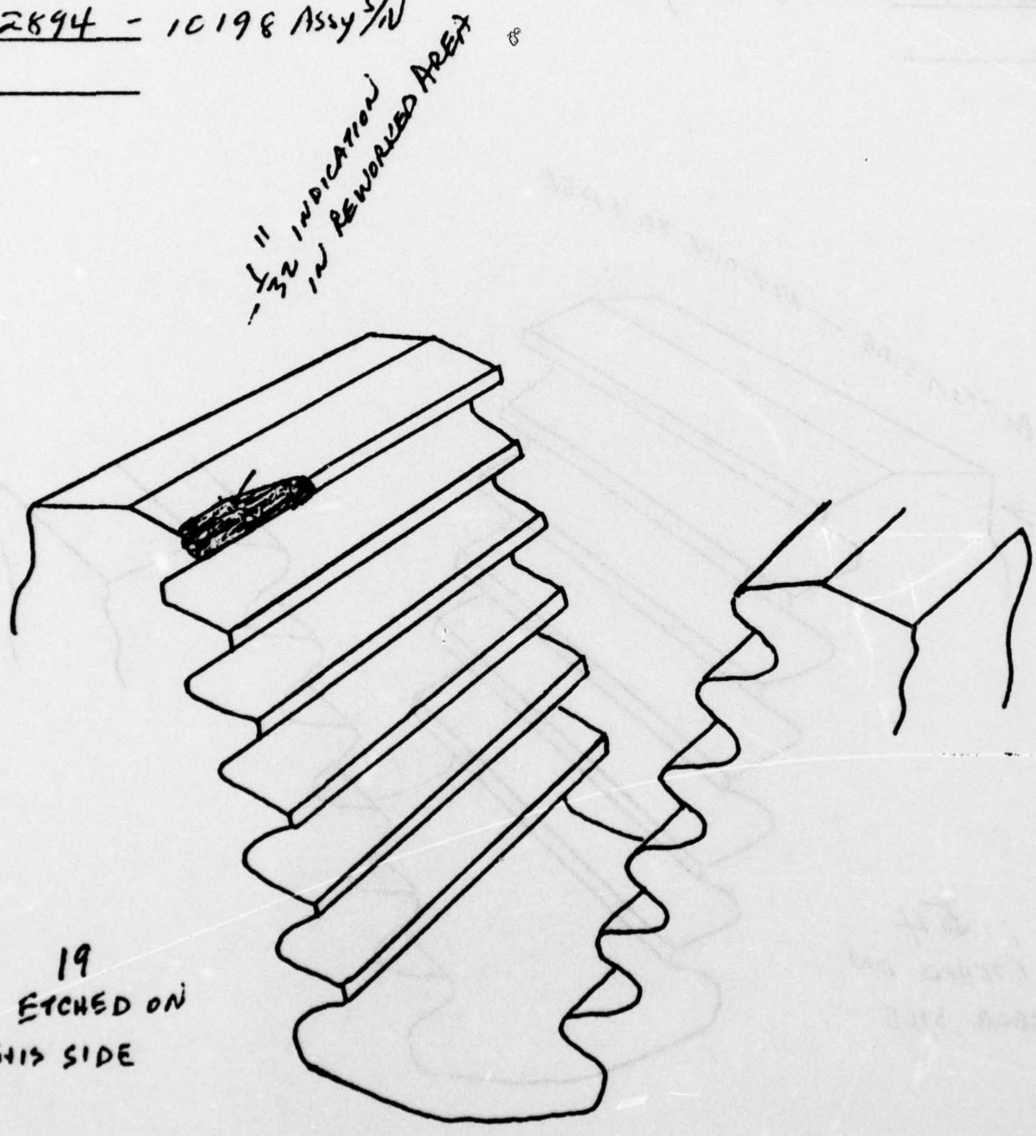
TF41 BLADE SERRATIONS

Unit 142163 TD________ Inspector NICELY Date 1-24-78

P/N 6861135

S/N 2894 - 10198 Assy S/N

Pos.________



REAR SIDE

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

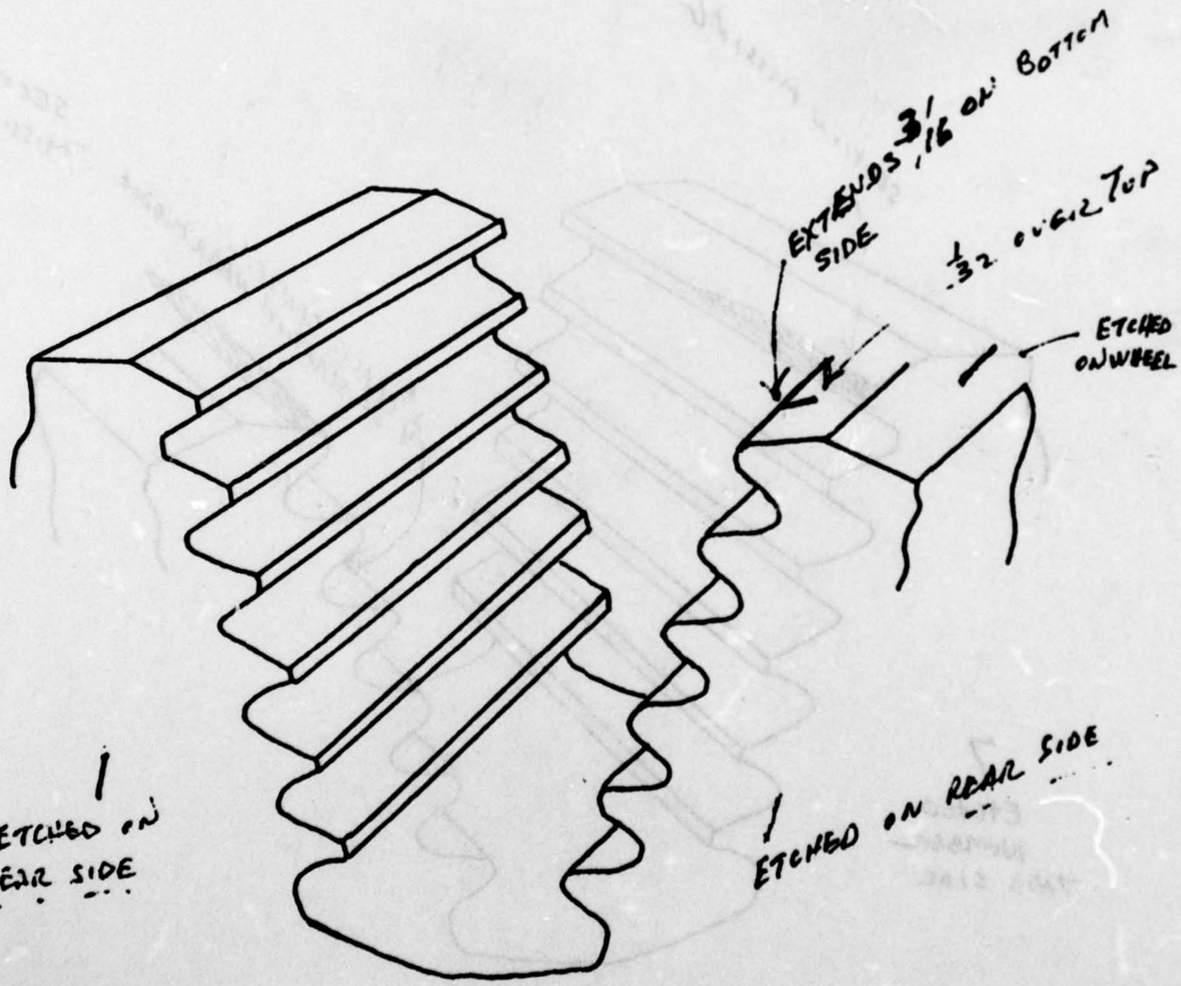
TF41 BLADE SERRATIONS

Unit '42163 TD_____ Inspector NICELY Date 1-24-75

P/N 6861135

S/N 2894 10198 Assy S/N

Pos._____



FRONT SIDE

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

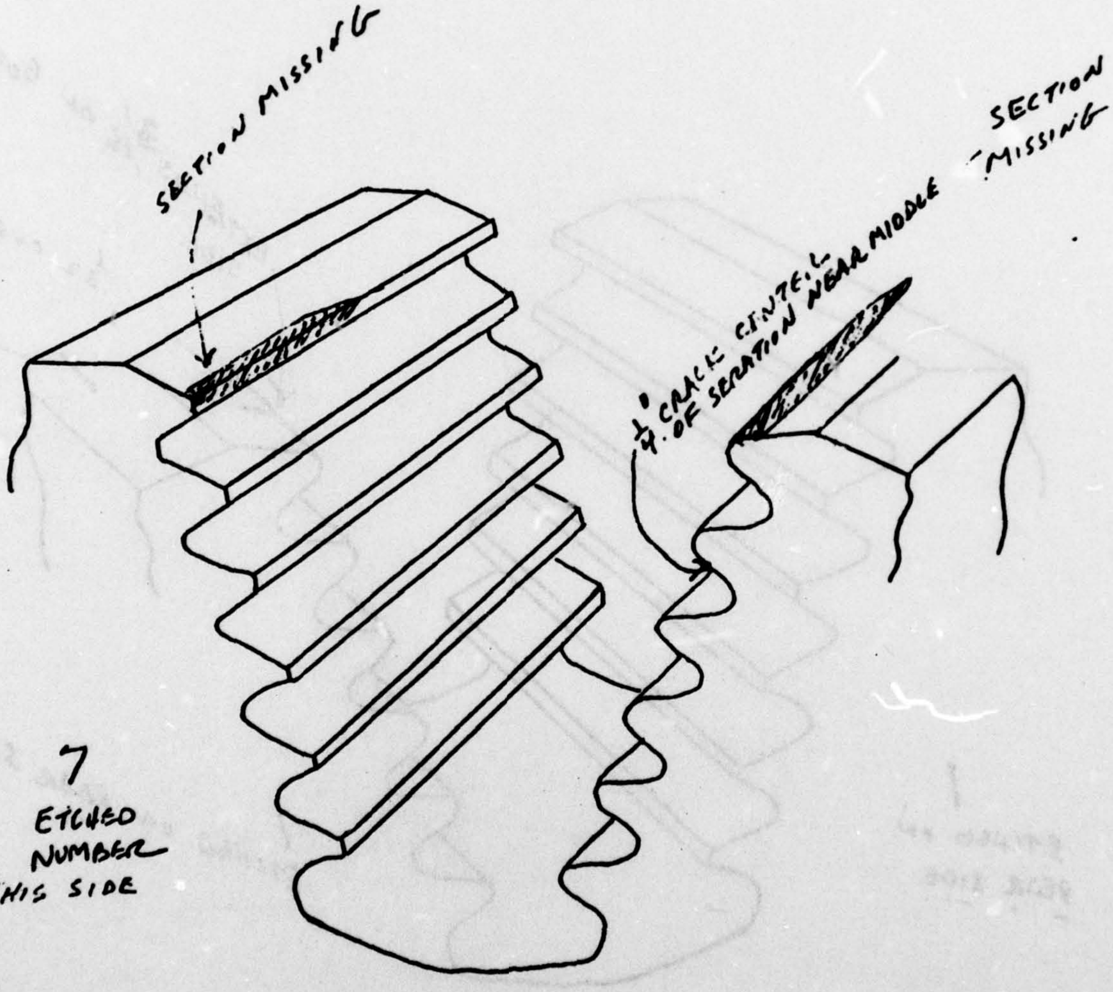
TF41 BLADE SERRATIONS

Unit 142163 TD ________ Inspector NICELY ________ Date 1-24-78

P/N 686 1135

S/N 2894 -- 10198 ASSY s/n

Pos. ________



AFT SIDE OF WHEEL

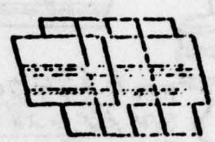
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 2nd Stage Blades - Zyglo Results

Unit 142163 TD. 1 Inspector [illegible] Date 1-25-78
Ref: P/N 6865938

Leading Edge

These blades, [illegible] cracked [illegible] blades, but all [illegible] have damage or [illegible] in this area.

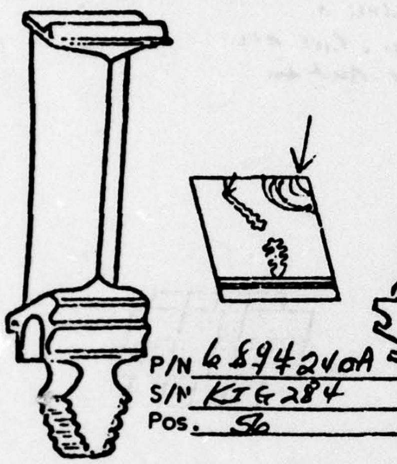


S/N	Position	S/N	Position
R368575	54		
R367296	52		
R345648	50		
R3[illegible]766	49		
R343269	48		
R353778	43		
R303438	46		

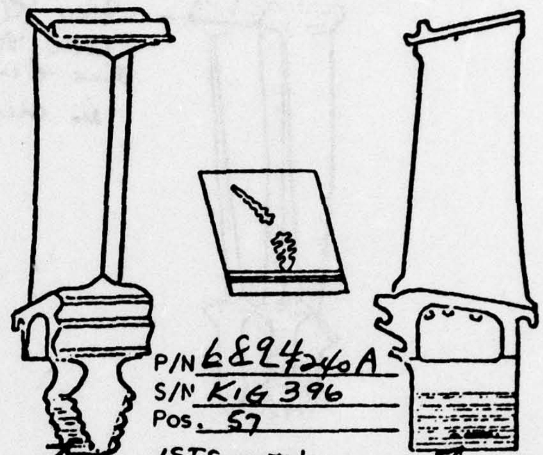
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE Ref: 6878291

Unit 142163 T.D. 1 Inspector [signature] Date 1-25-78



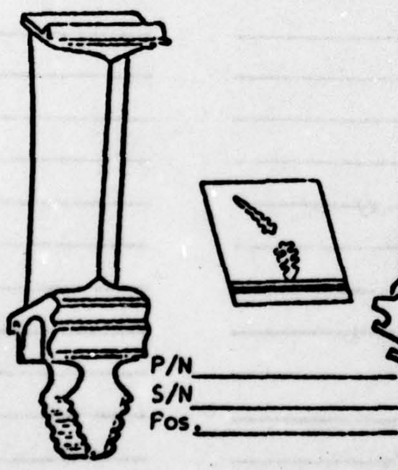
P/N 6894240A
S/N KIG284
Pos. 56



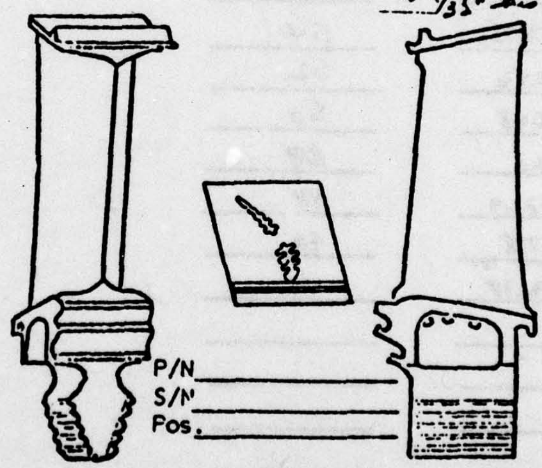
P/N 6894240A
S/N KIG 396
Pos. 57

1ST Serration.

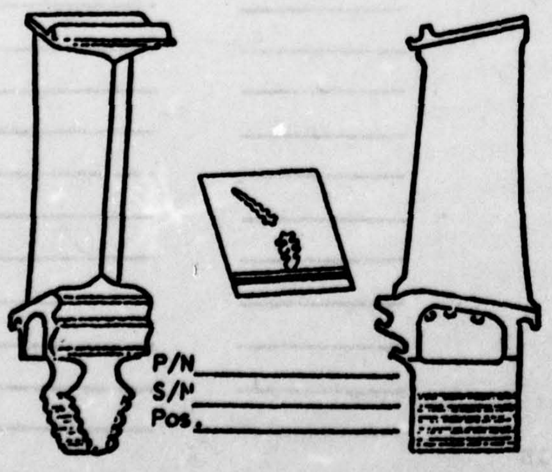
1/8" opposite side
1/32" this side



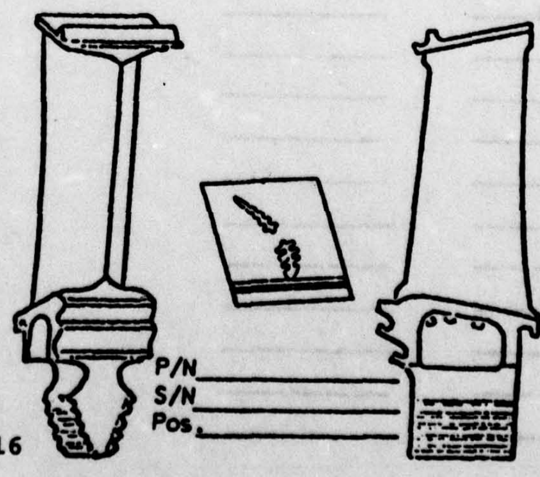
P/N
S/N
Pos.



P/N
S/N
Pos.



P/N
S/N
Pos.



P/N
S/N
Pos.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

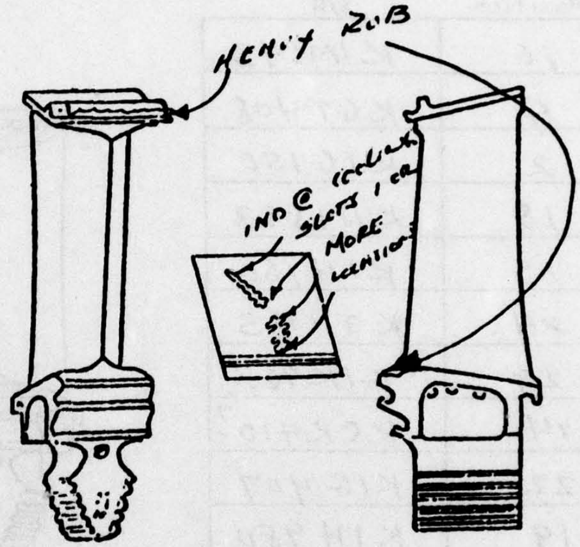
TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6861247

Unit 142163 T.D. 1 Inspector [illegible] Date 1-25 78

Blade P/N 6894740 has indications as shown.

Position	S/N
97	K1G 275
99	K1G 738
95	KGC 088
100	KES 735
92	KGR 706
91	K16107
98	K13257
93	K16613
94	KIJ 913
96	K16852
87	K21170



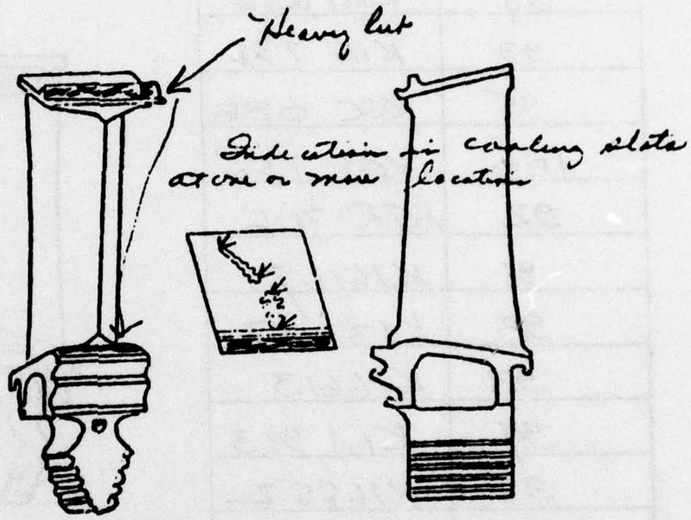
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE Ref: 6878291

Unit 142163 T.D. 1 Inspector Theily - Bruhn Date 1-25-78

Blade P/N 6894240 has indications as shown.

Position	S/N
10	K1M643
4	KGT408
2	K1G150
18	K1M883
15	K1H160
24	KTH183
28	K1K963
14	KCR410?
22	K1G407
19	K1H980
11	KG-141
5	KGR652
12	K1G421
9	K1G305
21	K1M079
20	K1J604
26	K11596
1	K1G089
31	K1F720
17	K1J772
16	K1K910
3	KGT360
8	KGH861
7	K1M101



23 - K11621
27 - KGT376
6 - KGS986
32 - K11088
13 - KII587

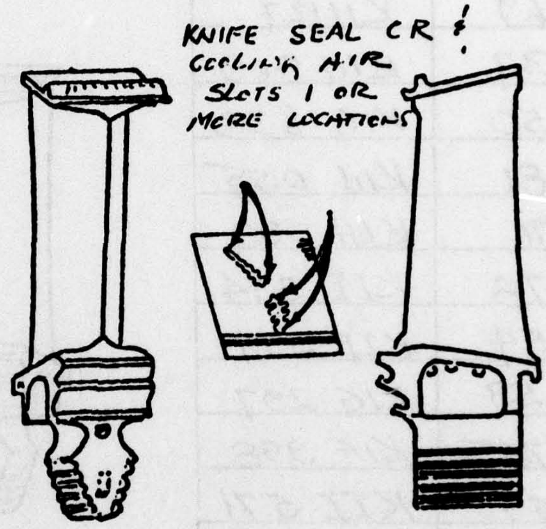
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

T141 - H.P. TURBINE - 1st STAGE BLADE Ref: 6861247

Unit 142163 T.D. 1 Inspector [illegible] Date 1-25-78

Blade P/N 6529290 has indications as shown.

Position	S/N
35	KTI 1601
39	KGS 721
79	KGP 015
41	KIK 164
80	KIH 161
82	KIM 871
73	KGP 750
43	KIH 787
51	KIF 757
88	KTI 600



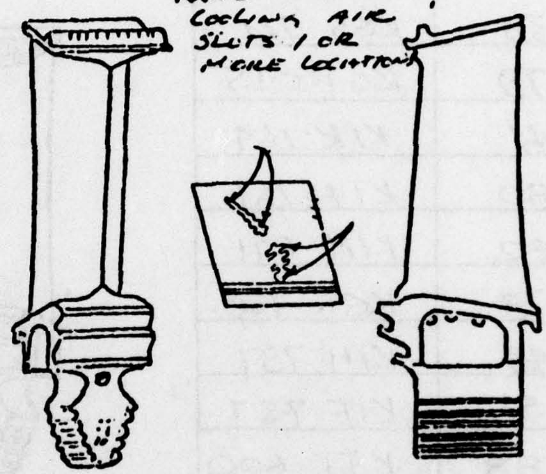
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE Ref: 6861247

Unit 142163 T.D. 1 Inspector [illegible] Date 1-25-78

Blade P/N 6894246 has indications as shown.

Position	S/N
69	KI1127
37	KIG 869
50	KIG 833
81	KIJ 055
70	KIH 597
78	KII 574
54	KII 577
53	KIG 297
75	KIF 998
43	KII 571
86	KGK 674
74	KGP 941
52	KI6669
46	KIJ 796
55	KGT 936
44	KGP 011
48	KI11795
36	KIK 911
89	KIG 081
90	~~~
41	KI6790
42	KIM 825
45	KJ 111
83	KIJ 912



EXPERIMENTAL ASSEMBLY & TEST INSPECTION

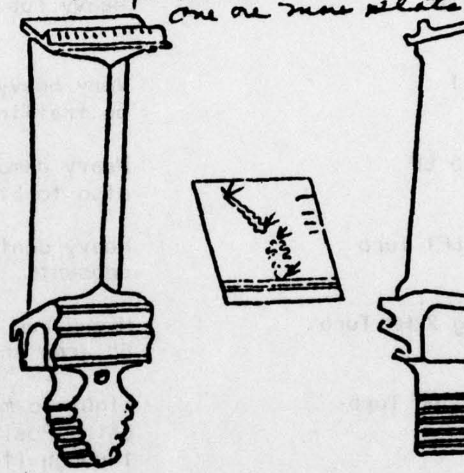
TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6878291

Unit 142163 T.D. 1 Inspector Neely - Fisher Date 1-25-78

Blade P/N 6894240 has indications as shown.

Blades With No rub.
Indications in cooling slots and Knife seal cracks. Indication in one or more slots.



Position	S/N
63	KTH 954
59	KIF 691
29	KIG 670
65	KJH 648
34	KIK 010
64	KTT 593
61	KIJ 195
67	KGT 029
60	KIH 695
33	KIJ 038
66	KIG 509
25	KIH 042
30	KIG 035
62	KIS 769?
68	KIL 943
58	KIM 014
77	KG 5456
72	KI 6658
76	KGP 168
38	KGJ 0223
58	KGP 637
84	KGT 407
40	KIK 149
71	KTH 623

FORM 0000 (?/??)

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 1 MODEL TF41 T.D. DATE 31 January 1978

Wright Patterson Engine

INSPECTORS Duckett/Fattic TOTAL TIME 110:00 ENDURANCE TIME

dl

REASON FOR T.D. Internal Failure

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Ring-LP2 Nozzle P/N 6861039	Heavy rub wear and torn in ID.
Vane-LPT Stg 1 P/N 6891839	Very heavy damage and large sections missing on trailing edge at outer band.
Rotor Asm-Turb LP P/N 6867969	Heavy damage to LP blades in Stg 1 and 2; also to Stg 2 LP vanes.
Seal Segment-LP1 Turb P/N 6865635	Heavy dents, gouges and nicks in ID of eleven segments.
Seal-Outer Stg 2 HP Turb P/N 6865031P	Heavy rub on OD of smaller labyrinth seal with 6" area and two knife seals worn away.
Seal Seg-Stg 2 HP Turb P/N 6865628F	Light to medium rub and pickup in ID of blade path; Position 9 has 1" x 3/8" hole gouged through it in blade path.
Vane Asm-HP2 Turb P/N 6866849	Three vane segments have cracks on concave side of one vane. One vane has two cracks on concave side near outer band, 1/2" to 3/4" long.
Extn Asm-LP Compr Inlet P/L P/N 6895779	Helicoil coming out at air control mounting in ID of inlet.
Fairing Support Asm-LP Turb P/L P/N 6866791	Very heavy damage to fairing support in ID... dents, tears and gouges.
Seal-Air HP2 Turb P/N 6864010A	Medium grooving and pickup in center area ID.
Liner & Nozzle Asm-Comb, Pos. 1 P/N EX125311, Liner S/N SLE330A Nozzle S/N SD55862	Light fretting in ID of fuel nozzle hole. Light fretting on connector. Light fretting on nozzle flanges.
Liner & Nozzle Asm-Comb, Pos. 2 P/N EX125312, Liner S/N SLE218A Nozzle S/N SD55635	Three smoke chutes have medium erosion. Fretting spot in ID of fuel nozzle hole. Heavy fretting on connector. Heavy fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 3 P/N EX125311, Liner S/N SLF305A Nozzle S/N SD35835	Two smoke chutes have light erosion. Fretting in ID of fuel nozzle hole. Fretting spots on connector. Fretting on nozzle flanges.

FORM 1050 REV 8/71

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 TD 1 MODEL TF41 TD DATE 31 Janaury 1978

INSPECTORS ________ TOTAL TIME ________ ENDURANCE TIME ________

REASON FOR T D ________

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Liner & Nozzle Asm-Comb, Pos. 4 P/N EX125313, Liner S/N SLE8919 Nozzle S/N SD54170	Two smoke chutes have light erosion. Fretting in fuel nozzle hole ID. Fretting on nozzle hole ID. Fretting on nozzle flanges. Crack in weld at crossover tube mounting flange.
Liner Asm-Comb, Pos. 5 P/N 6862239, S/N SLF328	Fretting in ID of nozzle hole. One smoke chute has light erosion. Two cracks at crossover tube mounting flange.
Liner & Nozzle Asm-Comb, Pos. 6 P/N EX125312, Liner S/N SLF237 Nozzle S/N SD55750	Fretting in ID of nozzle hole. Two cracks at crossover tube mounting flange. Fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 7 P/N EX125311, Liner S/N SLF320 Nozzle S/N SD55900	Crack at crossover tube mounting flange. Fretting on connector. Fretting spots on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 8 P/N EX125314, Liner S/N SLF146 Nozzle S/N SD55269	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flanges. Fretting on nozzle flanges. Fretting on connector.
Liner & Nozzle Asm-Comb, Pos. 9 P/N EX125311, Liner S/N SLF61 Nozzle S/N SD55382	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flange. Fretting spots on connector. Fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 10 P/N EX125312, Liner S/N SLF245 Nozzle S/N SD55784	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flanges. Fretting on nozzle flanges.
Shaft-Rotor & Blades Asm-HPT Stg 1 P/N 6894579, S/N 12583	Ten blades have medium rub and pickup on forward knife seal at platform. Several other blades have medium rub at wear on shroud's seal area. Wheel and shaft seals have medium rub areas with pickup.
Vanes-HPT Stg 1 P/N --	Several vanes have cracks on trailing edge at outer band with light erosion on trailing edge center area on some.
Seal Asm, Intermediate-HP Thrust Brg P/N 6888736A	The seal insert seized on HP shaft of compressor. Three spot welds were broken during removal of seal from compressor rotor.
Wheel Asm-HPT Stg 2 P/N 6861136, S/N 10198	The right hand blade of #7 paired blades broke off in wheel dovetail. Wheel dovetail has two pieces of wheel broken off on OD; one piece on each side.

FORM 1050(REV 5/71)

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 1 MODEL TF41 T.D. DATE 31 January 1978

INSPECTORS ______ TOTAL TIME ______ ENDURANCE TIME ______

REASON FOR T.D. ______

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Blade-HPT Stg 2 P/N 6869079	Piece of blade bottoms from three dovetails was found in wheel serration at teardown.
LP Compr Case & Vane Asm P/N 6848466A, Set S/N 1406	Three vanes in Stg 2 top case have coating peeling off.
Vane Asm-IP Outlet Guide P/L P/N 6869580	Medium to heavy wear and rub in ID of seal area.
Seal Sleeve LP Turb Brg P/N 6878262	Medium to heavy wear on OD of seal knives.

This completes the report. Any additional information will be submitted as another addendum.

S/N 142163/1A

FORM 10S01REV 8/71

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 1 MODEL TF41 T.D DATE 31 January 1978

Wright Patterson Engine

INSPECTORS Duckett/Fattic TOTAL TIME 110:00 ENDURANCE TIME

REASON FOR T.D. Internal Failure

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Ring-LP2 Nozzle P/N 6861039	Heavy rub wear and torn in ID.
Vane-LPT Stg 1 P/N 6891839	Very heavy damage and large sections missing on trailing edge at outer band.
Rotor Asm-Turb LP P/N 6867969	Heavy damage to LP blades in Stg 1 and 2; also to Stg 2 LP vanes.
Seal Segment-LP1 Turb P/N 6865635	Heavy dents, gouges and nicks in ID of eleven segments.
Seal-Outer Stg 2 HP Turb P/N 6865031P	Heavy rub on OD of smaller labyrinth seal with 6" area and two knife seals worn away.
Seal Seg-Stg 2 HP Turb P/N 6865628F	Light to medium rub and pickup in ID of blade path; Position 9 has 1" x 3/8" hole gouged through it in blade path.
Vane Asm-HP2 Turb P/N 6866849	Three vane segments have cracks on concave side of one vane. One vane has two cracks on concave side near outer band, 1/2" to 3/4" long.
Extn Asm-LP Compr Inlet P/L P/N 6895779	Helicoil coming out at air control mounting in ID of inlet.
Fairing Support Asm-LP Turb P/L P/N 6866791	Very heavy damage to fairing support in ID... dents, tears and gouges.
Seal-Air HP2 Turb P/N 6864010A - 2ws??	Medium grooving and pickup in center area ID.
Liner & Nozzle Asm-Comb, Pos. 1 P/N EX125311, Liner S/N SLE330A Nozzle S/N SD55862	Light fretting in ID of fuel nozzle hole. Light fretting on connector. Light fretting on nozzle flanges.
Liner & Nozzle Asm-Comb, Pos. 2 P/N EX125312, Liner S/N SLE218A Nozzle S/N SD55635	Three smoke chutes have medium erosion. Fretting spot in ID of fuel nozzle hole. Heavy fretting on connector. Heavy fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 3 P/N EX125311, Liner S/N SLF305A Nozzle S/N SD35835	Two smoke chutes have light erosion. Fretting in ID of fuel nozzle hole. Fretting spots on connector. Fretting on nozzle flanges.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

S/N 142163 T.O. 1 MODEL TF41 T.O. DATE 31 Janaury 1978

INSPECTORS ______ TOTAL TIME ______ ENDURANCE TIME ______

[illegible] ______

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Liner & Nozzle Asm-Comb, Pos. 4 P/N EX125313, Liner S/N SLE8919 Nozzle S/N SD54170	Two smoke chutes have light erosion. Fretting in fuel nozzle hole ID. Fretting on nozzle hole ID. Fretting on nozzle flanges. Crack in weld at crossover tube mounting flange.
Liner Asm-Comb, Pos. 5 P/N 6862239, S/N SLF328	Fretting in ID of nozzle hole. One smoke chute has light erosion. Two cracks at crossover tube mounting flange.
Liner & Nozzle Asm-Comb, Pos. 6 P/N EX125312, Liner S/N SLF237 Nozzle S/N SD55750	Fretting in ID of nozzle hole. Two cracks at crossover tube mounting flange. Fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 7 P/N EX125311, Liner S/N SLF320 Nozzle S/N SD55900	Crack at crossover tube mounting flange. Fretting on connector. Fretting spots on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 8 P/N EX125314, Liner S/N SLF146 Nozzle S/N SD55269	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flanges. Fretting on nozzle flanges. Fretting on connector.
Liner & Nozzle Asm-Comb, Pos. 9 P/N EX125311, Liner S/N SLF61 Nozzle S/N SD55382	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flange. Fretting spots on connector. Fretting on flanges of nozzle.
Liner & Nozzle Asm-Comb, Pos. 10 P/N EX125312, Liner S/N SLF245 Nozzle S/N SD55784	Fretting in ID of fuel nozzle hole. Two cracks at crossover tube mounting flanges. Fretting on nozzle flanges.
Shaft-Rotor & Blades Asm-HPT Stg P/N 6894579, S/N 12583	Ten blades have medium rub and pickup on forward knife seal at platform. Several other blades have medium rub at wear on shroud's seal area. Wheel and shaft seals have medium rub areas with pickup.
Vanes-HPT Stg 1 P/N --	Several vanes have cracks on trailing edge at outer band with light erosion on trailing edge center area on some.
Seal Asm, Intermediate-HP Thrust Brg P/N 6888736A	The seal insert seized on HP shaft of compressor. Three spot welds were broken during removal of seal from compressor rotor.
Wheel Asm-HPT Stg 2 P/N 6861136, S/N 10198	The right hand blade of #7 paired blades broke off in wheel dovetail. Wheel dovetail has two pieces of wheel broken off on OD; one piece on each side.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

ENT. 142163 T.O. 1 MODEL TF41 T.O. DATE 31 January 1973

TOTAL TIME ENDURANCE TIME

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Blade-HPT Stg 2 P/N 6869079	Piece of blade bottoms from three dovetails was found in wheel serration at teardown.
LP Compr Case & Vane Asm P/N 6848466A, Set S/N 1406	Three vanes in Stg 2 top case have coating peeling off.
Vane Asm-IP Outlet Guide P/L P/N 6869580	Medium to heavy wear and rub in ID of seal area.
Seal Sleeve LP Turb Brg P/N 6878262	Medium to heavy wear on OD of seal knives.
#5 HP THRUST BRG.	?

This completes the report. Any additional information will be submitted as another addendum.

FORM #0000 8/71

EXPERIMENTAL ASSEMBLY & TEST INSPECTION TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 2 MODEL TF41 T.D. DATE 20 April 1978

INSPECTORS Duckett/Fattic/Fisher/Toms TOTAL TIME ENDURANCE TIME

dl

REASON FOR T.D.

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Vane Asm-HPT Stg 1 P/N 6894686 - 60 pieces Bulkwell Vanes	Zyglo charts reflect the detail parts of the above listed assembly. All vanes have broken weld joints.
Vane-LPT Stg 1 P/N 6892960 - 13 pieces	Position 6, S/N 14840, LH vane (C1354) has a large metal particle inside tube blocking air flow...seems to be brazed to tube. (NOTE: Metal was removed, 26 April.) Zyglo OK
Vane Asm-HPT Stg 2 P/N 6868836, S/N 776-30	Borescope inspection revealed indications as charted on page 17.
Vane Asm-HPT Stg 2 P/N 6868849 - 21 pieces	Zyglo indications as charted on pages 17 through 22.
Vane-LPT2 P/N 6860042	Vane S/N C04872 cracked at locating hole.
Wheel Asm-LPT Stg 1 P/N 6867966, S/N 10080	Zyglo OK.
Wheel & Shaft Asm-LPT Stg 2 P/N 6865081, S/N 10074	Checked serrations...shaft not removed from wheel and not inspected. Zyglo OK.
Blades-LPT Stg 1 P/N 6865616 - 109 pieces	Zyglo OK.
Blades-LPT Stg 2 P/N 6864002 - 79 pieces	Zyglo OK.

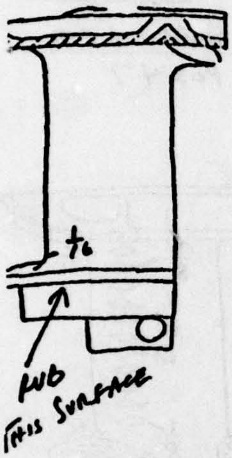
This completes the report. Any additional information will be submitted as an addendum.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm.

Unit 142163 TD 2 Inspector [illegible] Date 4-21-78

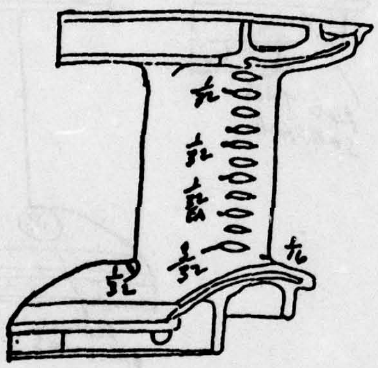
VANES ARE DETAILS OF 6894686 ASSY.

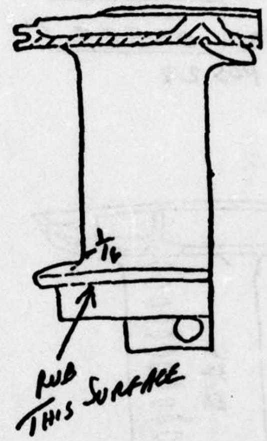


P/N

S/N C01066

POS 41

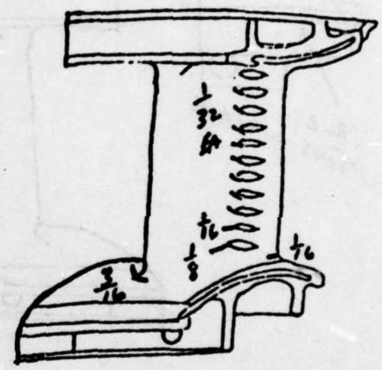


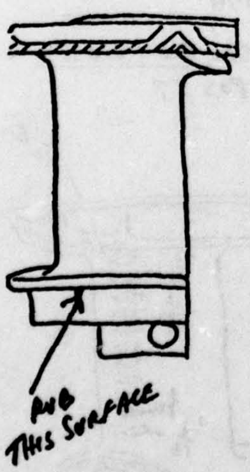


P/N

S/N C02608

POS 23

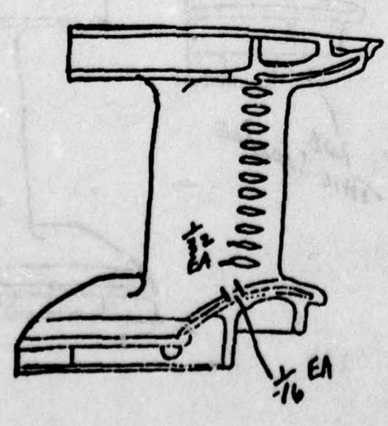


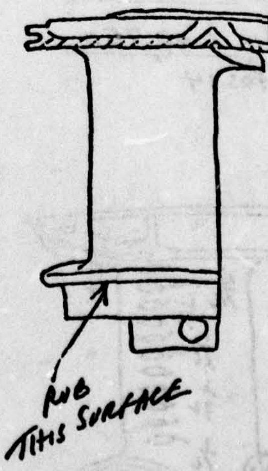


P/N

S/N 01729

POS 22 ?

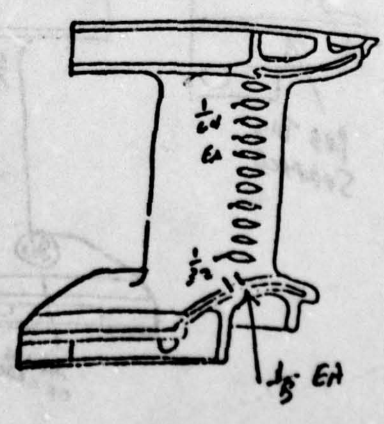




P/N

S/N 0602

POS 37



EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

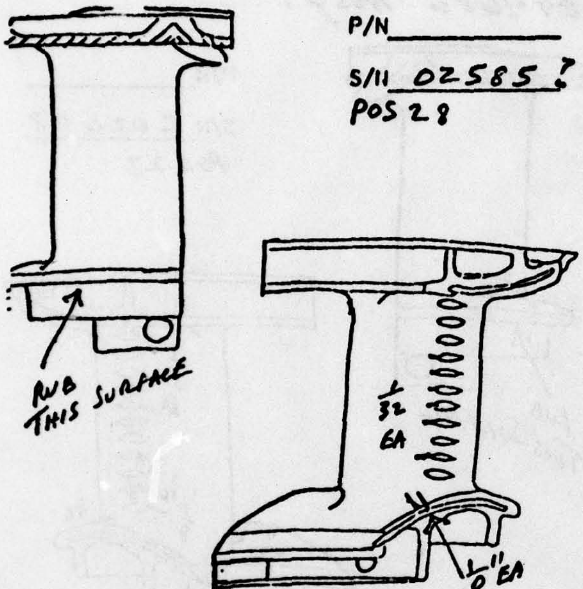
Unit 142163 TD 2 Inspector Rutischer Date 4-21-78

VANES ARE DETAILS OF 6844686 ASSYS.

P/N ______

S/N 02585 ?

POS 28



P/N ______

S/N C00989

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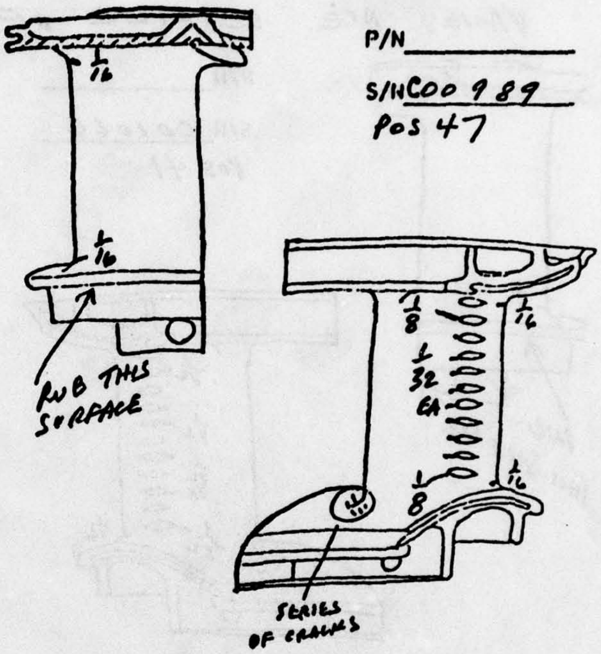

P/N ______

S/N C00750

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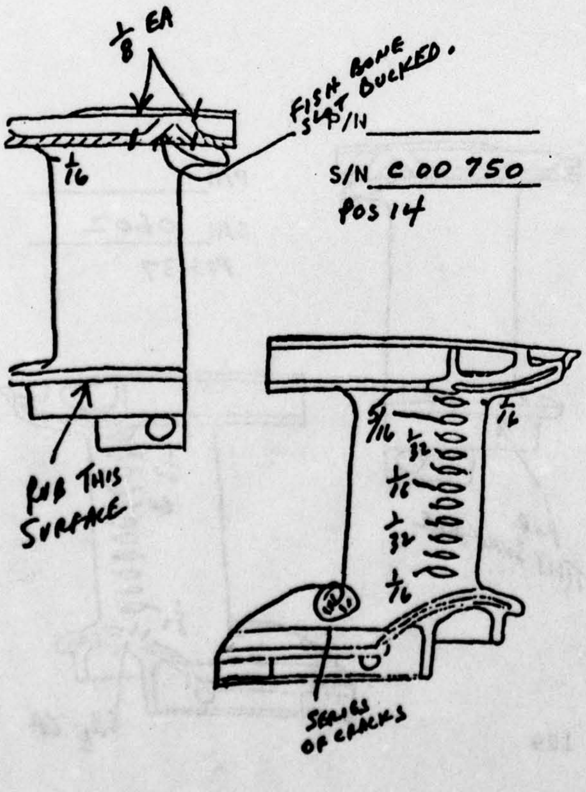

P/N ______

S/N C00608

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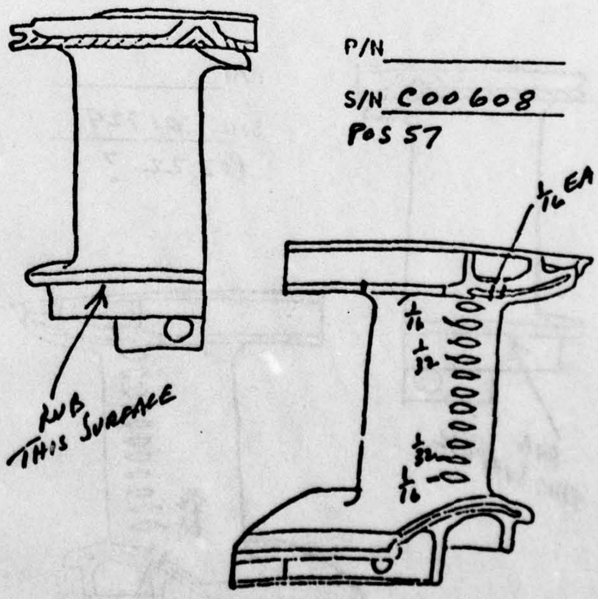


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

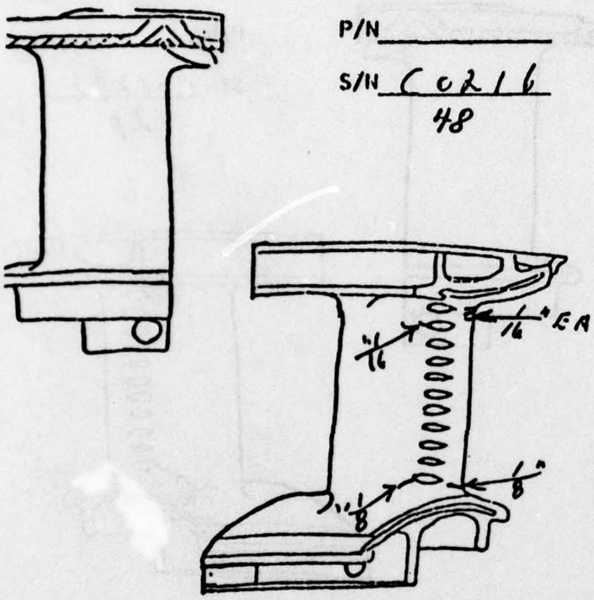
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector Fettke Date 4-20-78

VANES ARE DETAILS OF 6894686 ASSYS

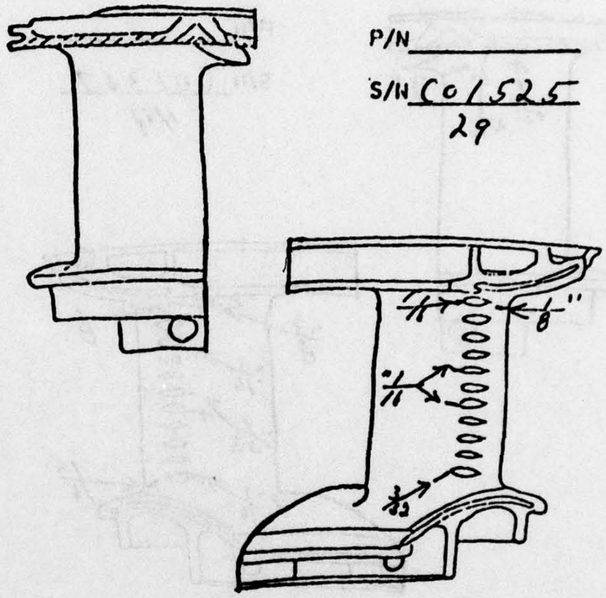
P/N ______

S/N C0216
48



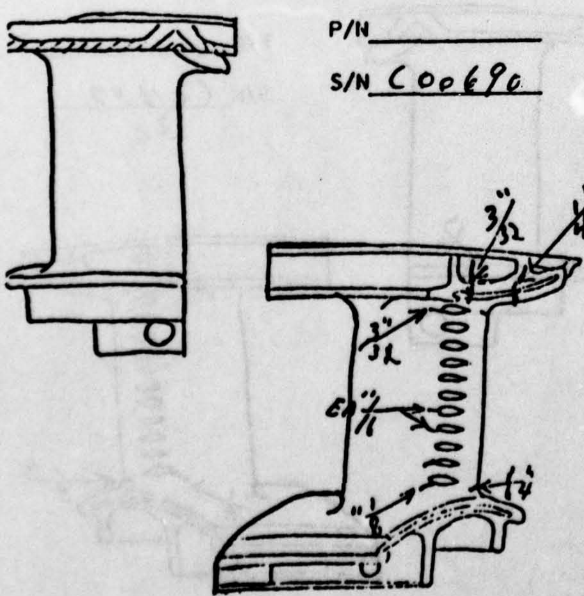
P/N ______

S/N C01525
29



P/N ______

S/N C00690



P/N ______

S/N C02263
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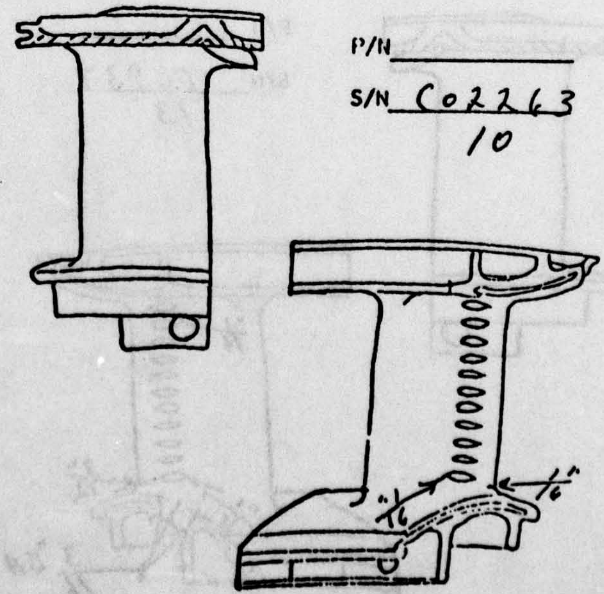


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

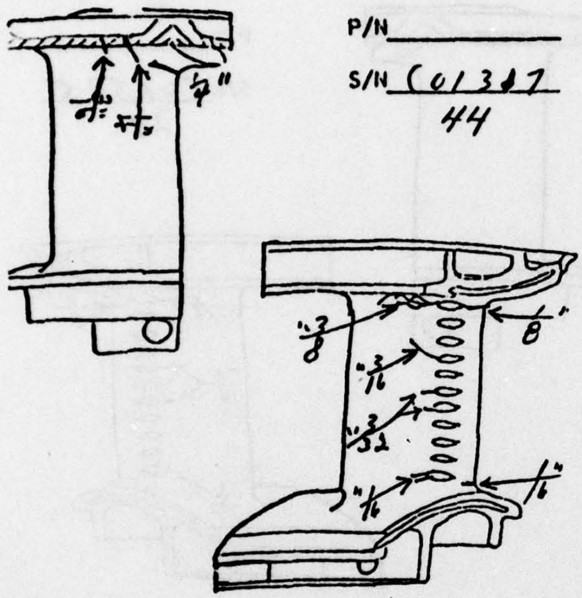
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector Fithie Date 4-20-78

VANES ARE DETAILS OF 6894686 ASSYS.

P/N

S/N C01387
44



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S/N C01292
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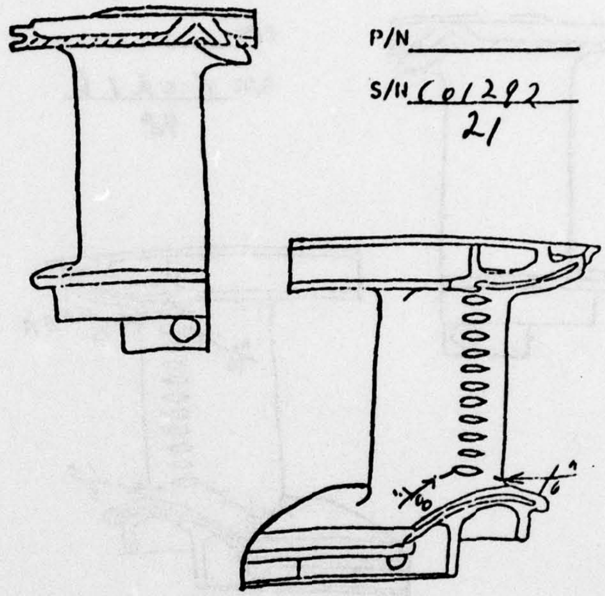

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S/N C0937
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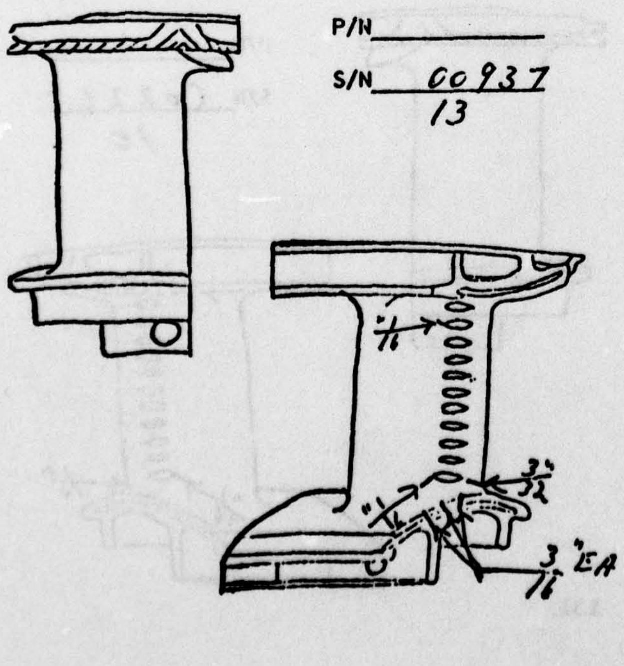

P/N

S/N C01192
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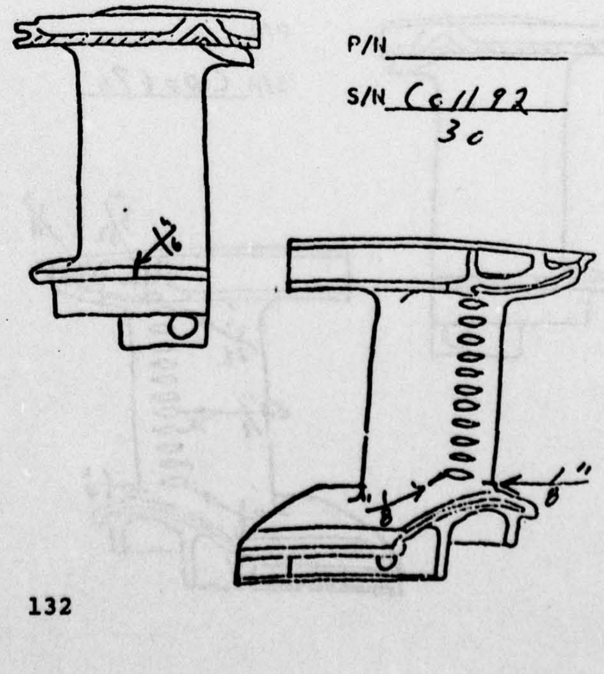


EXPERIMENTAL ASSEMOLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

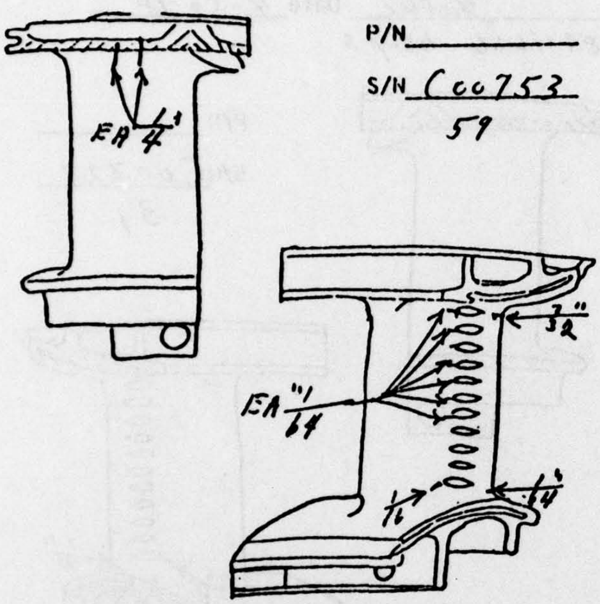
Unit 142163 TD 2 Inspector Fittie Date 4-20-78

VANES ARE DETAILS OF 6894686 ASSYS

P/N

S/N Co0753

59



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S/N Co1252

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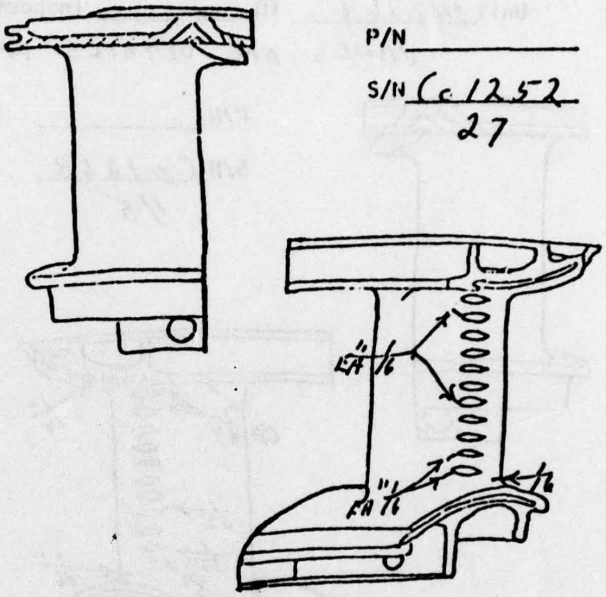
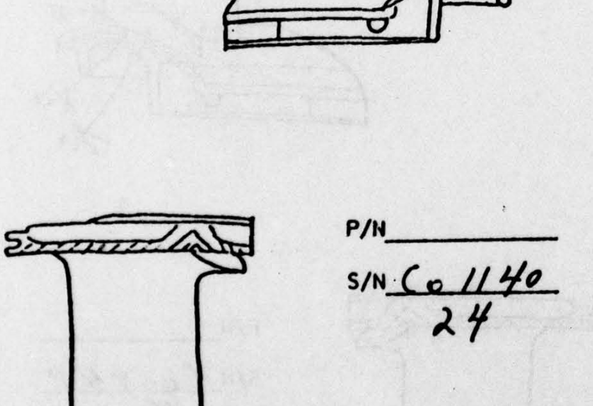


P/N

S/N Co1140

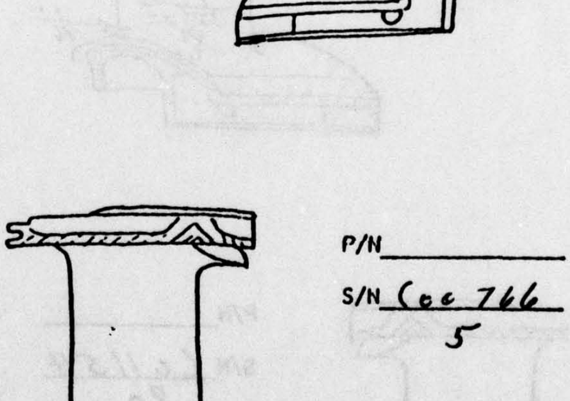
24



P/N

S/N Co0766

5



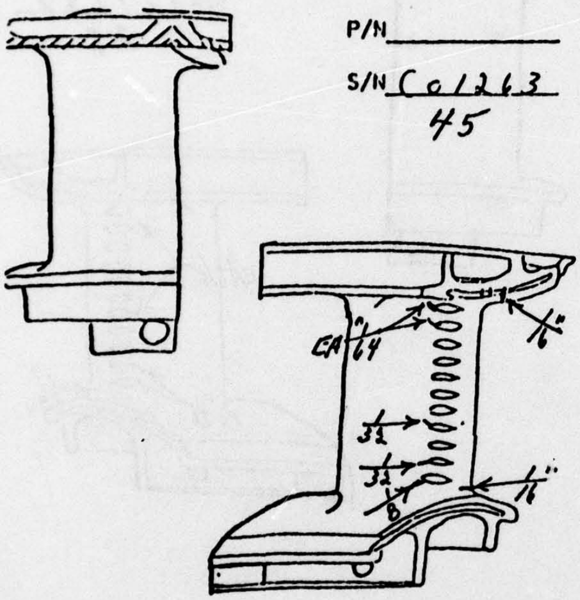
S/N 142163/2
Page 6 of 22

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector Fathie Date 4-20-78

VANES ARE DETAILS OF 6894686 ASSYS



P/N

S/N C01263

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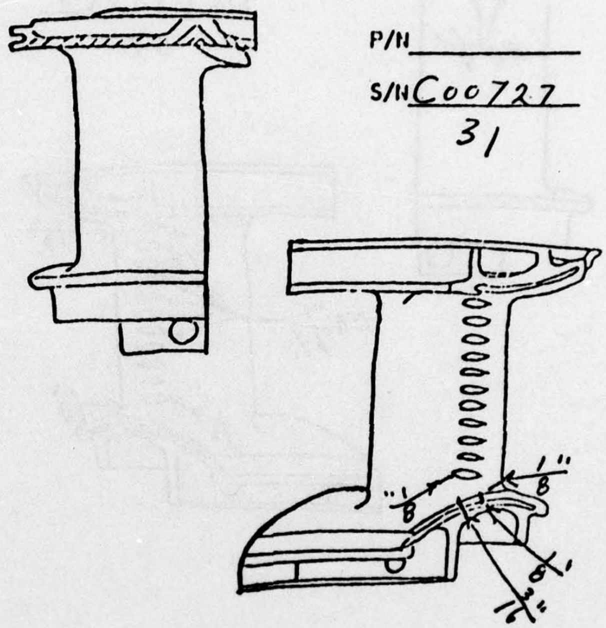

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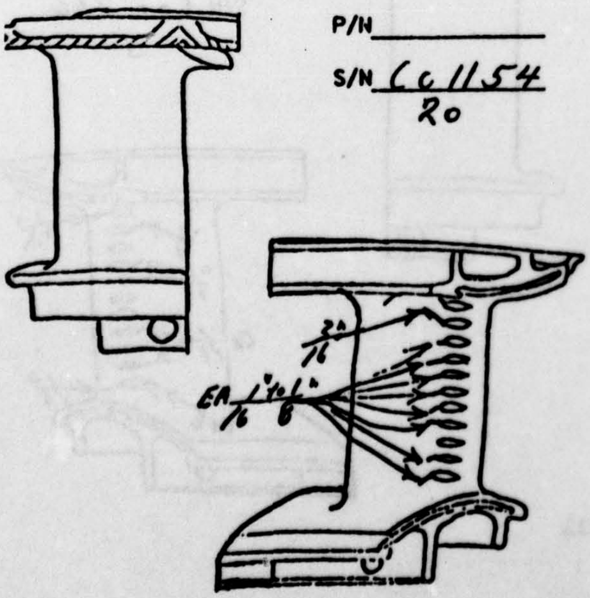

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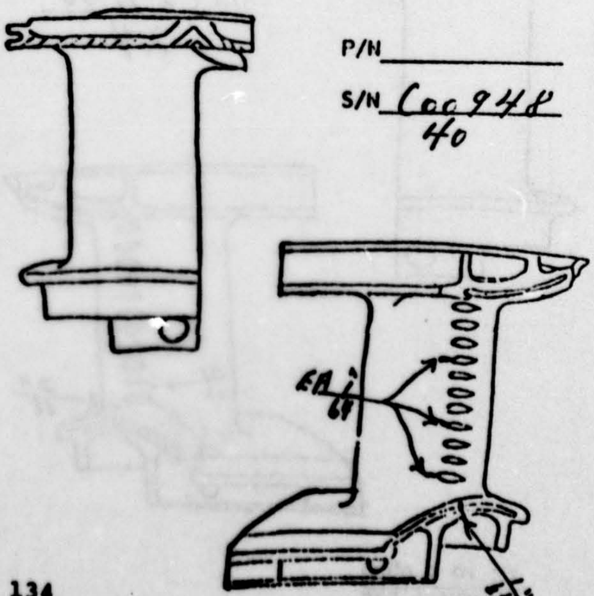

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S/N C00948

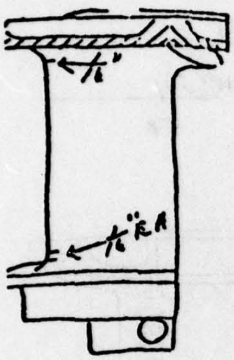
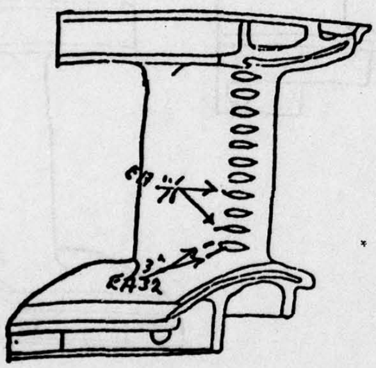
40

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector FATTIC Date 4-20-78

VANES ARE DETAILS OF 6894686 ASSYS.

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S/N C01265

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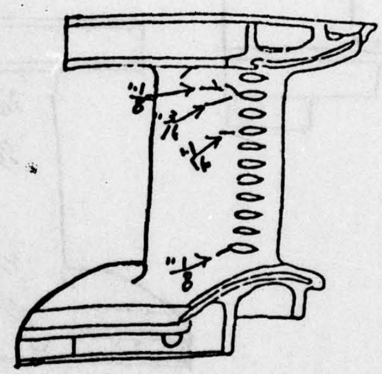

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S/N C02091

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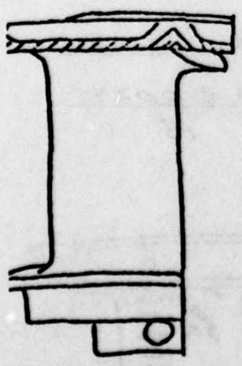
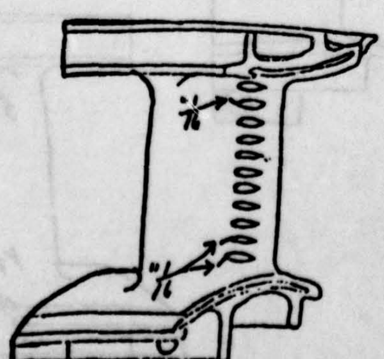

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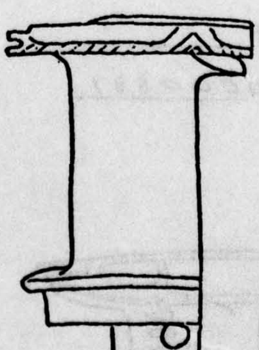
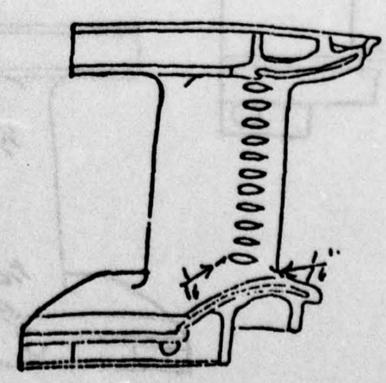



P/N ____

S/N C00584

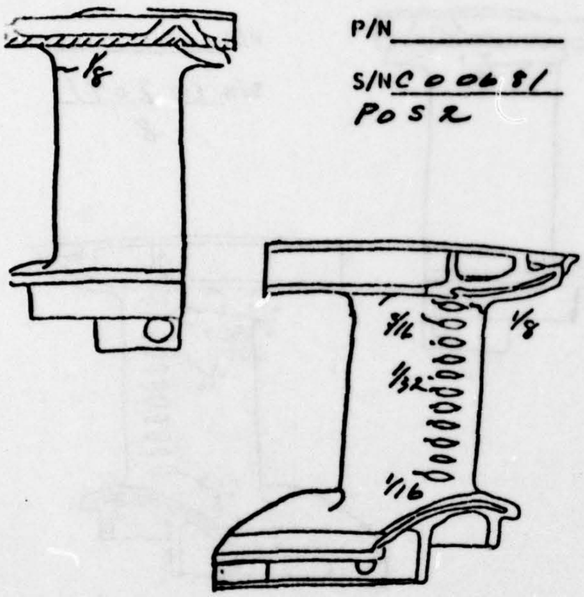
4

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector Toms Date 4-20-78

VANE ARE DETAIL PART OF 6894686 ASSY



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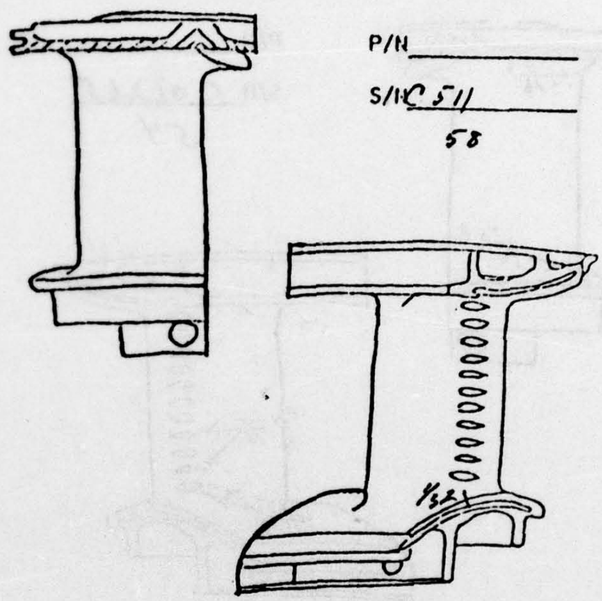
POS 2



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S/N C511

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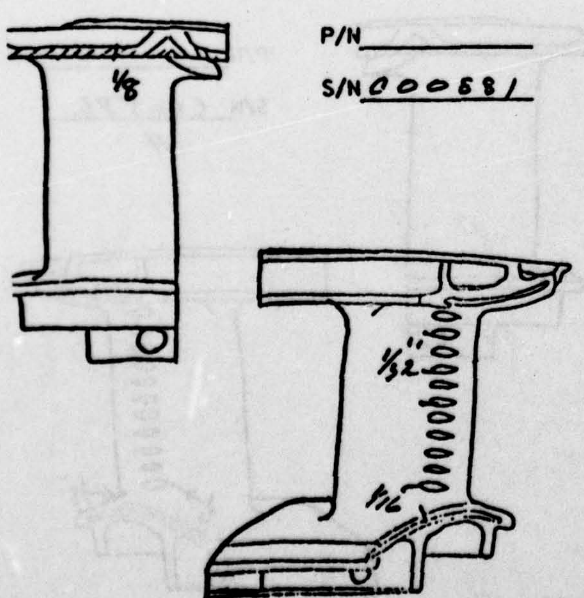

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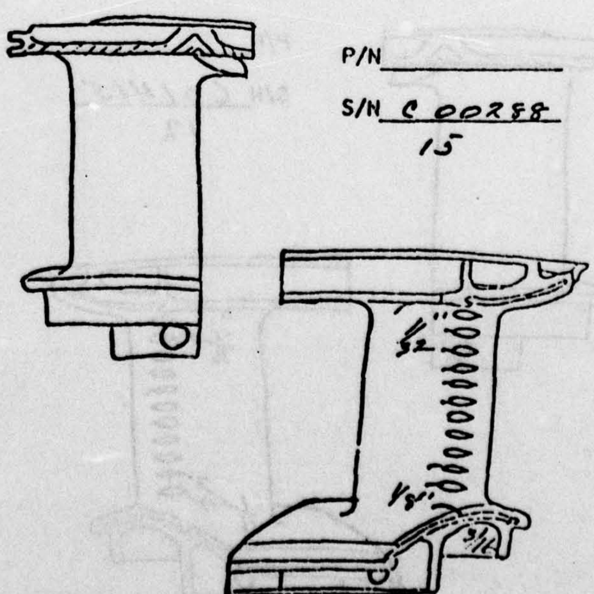


P/N ________

S/N C00288

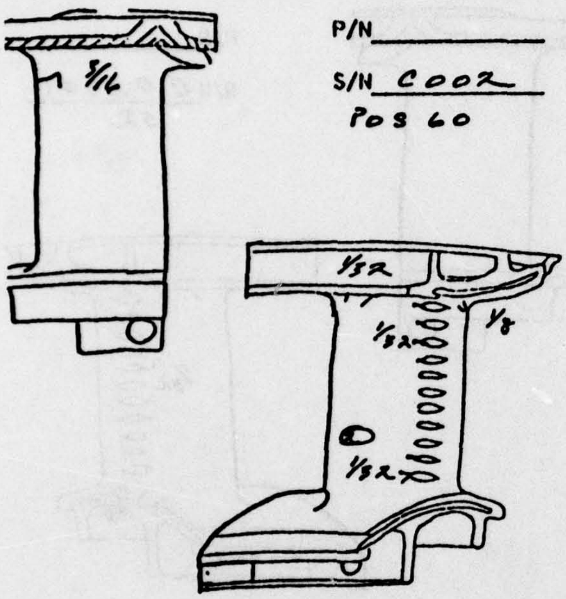
15

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector Toms Date 4-20-78

VANES ARE DETAIL PART OF 6894686 ASSY



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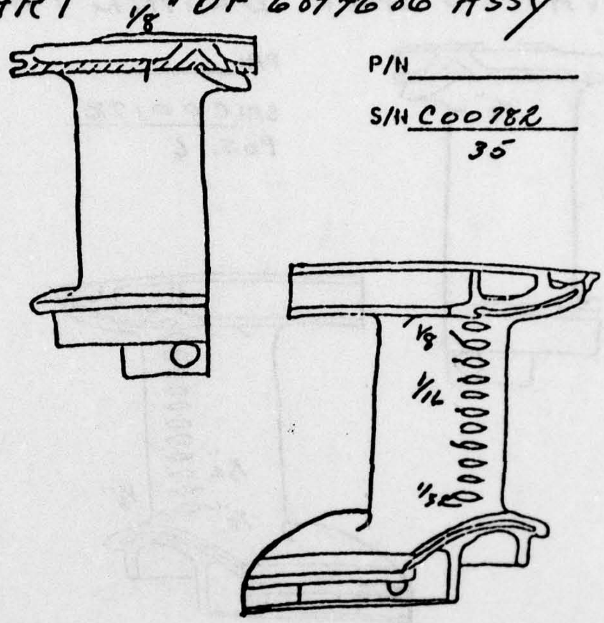
S/N C002
Pos 60



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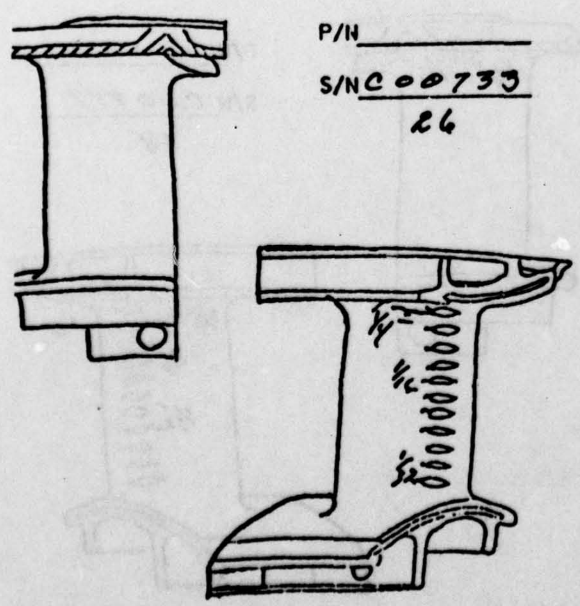

P/N

S/N C00733
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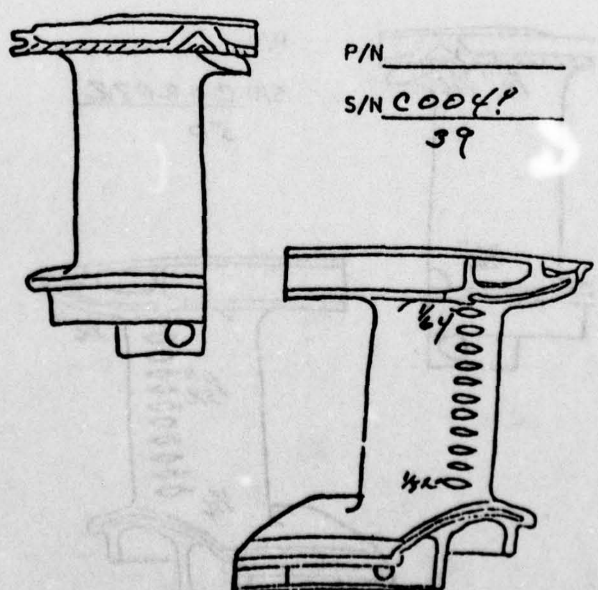


P/N

S/N C004?
39

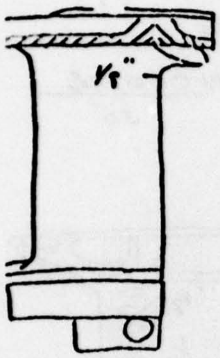
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

S/N 142163/2
Page 11 of 22

TF41 HP Turbine 1st Stage Vane Asm.

Unit 142163 TD 2 Inspector Toma Date 4-20-78

VANES ARE DETAIL PART OF 6894686 ASSY



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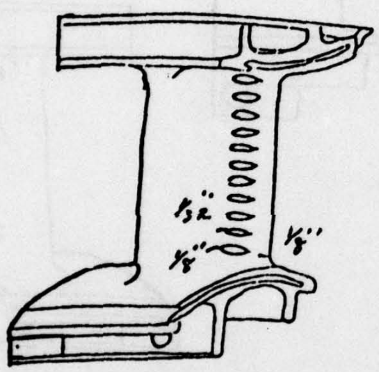
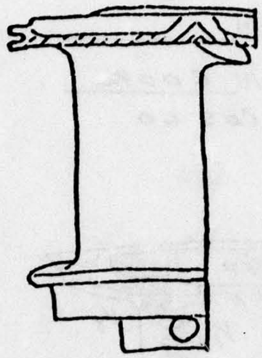
S/N C00172

Pos. 6





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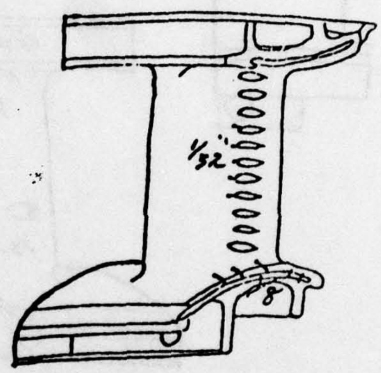

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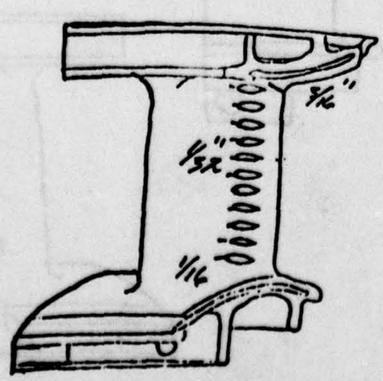

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S/N C00748

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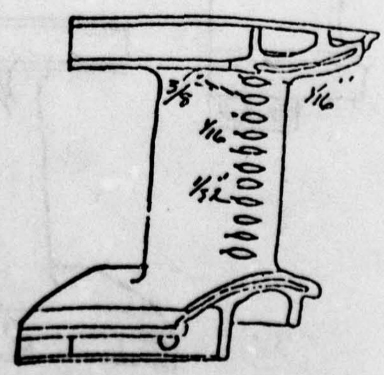
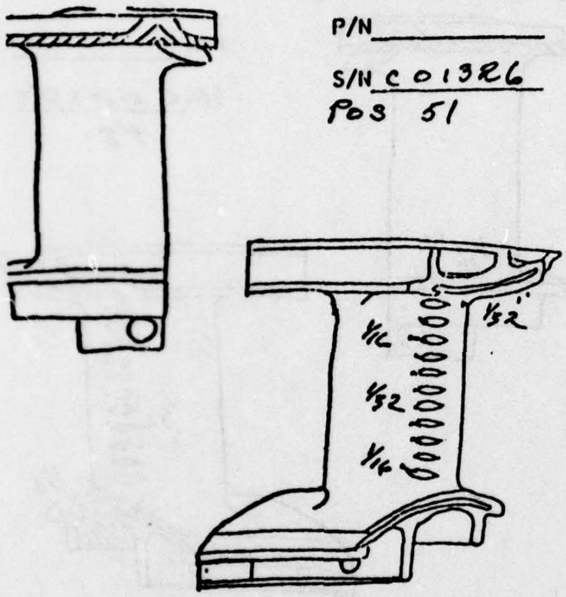


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142 163 TD 2 Inspector Jones Date 1-20-78

VANES ARE DETAIL PART OF 6894686 ASSY.



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S/N C01326
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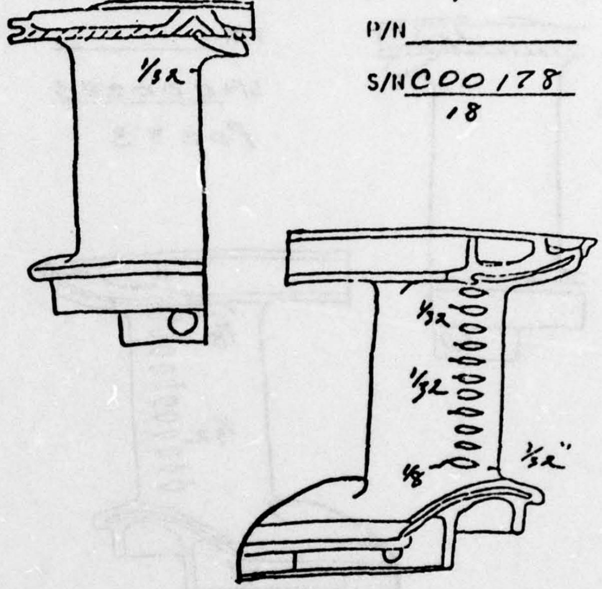

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S/N C00178
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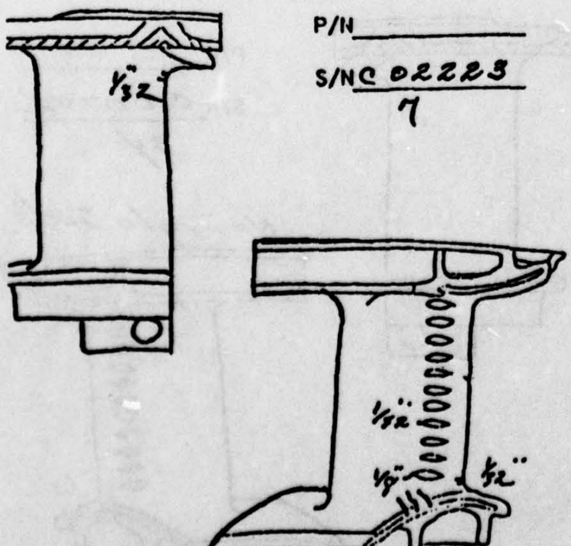

P/N

S/N C02223
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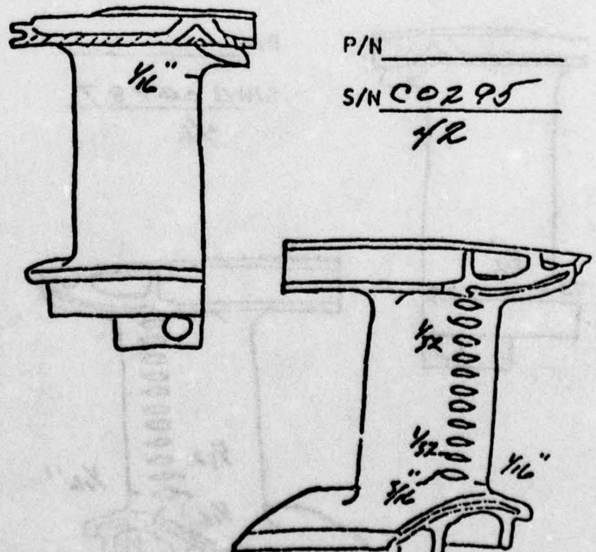


P/N

S/N C0295
42

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm .

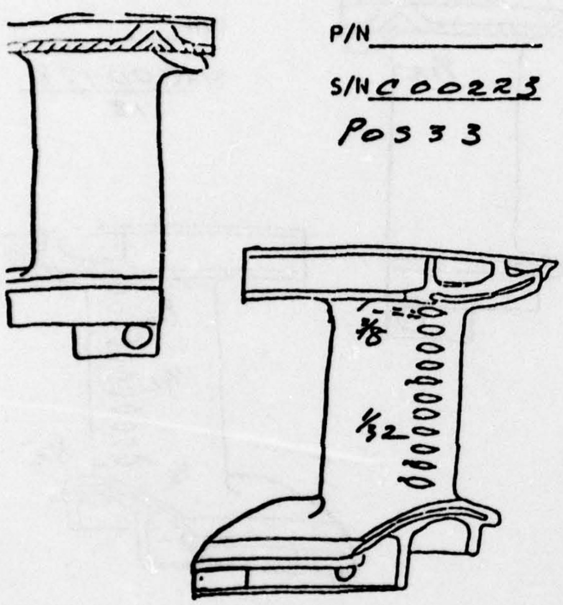
Unit 142163 TD 2 Inspector Tones Date 4-20-78

VANES ARE DETAIL PART OF 6894686 ASSY

P/N ____

S/N C 00223

Po 333



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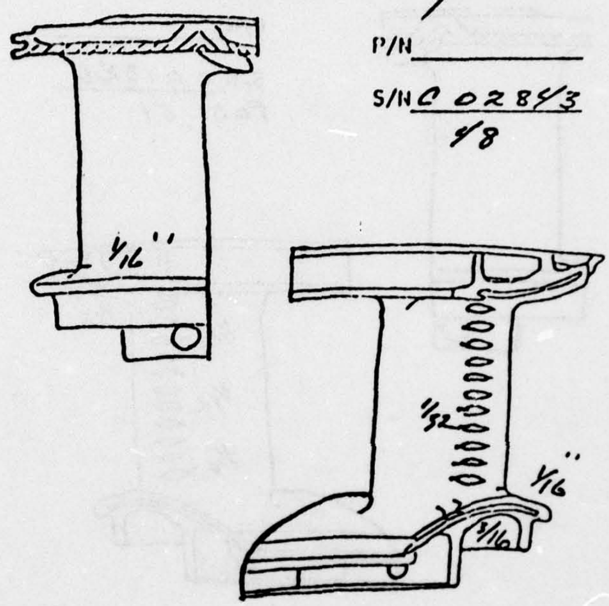
S/N C 02843

4/8



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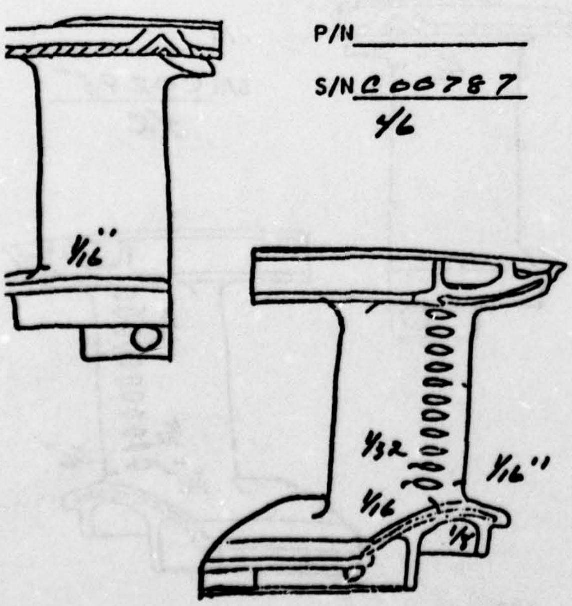
S/N C 00787

4/6



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S/N C 00742

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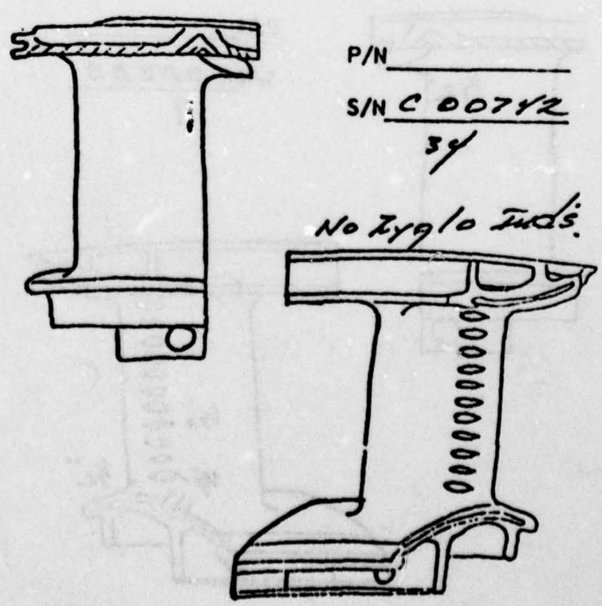
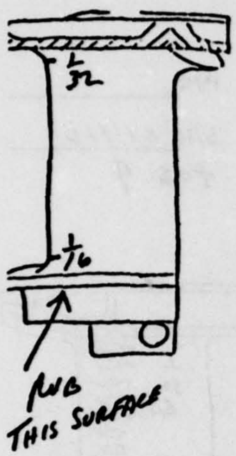


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TD 2 Inspector R. W. Fisher Date 4-21-78

VANES ARE DETAILS OF 6894686 ASSYS.



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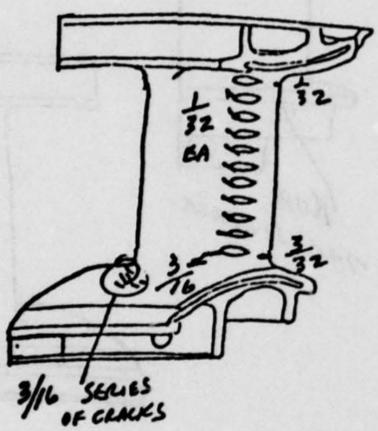
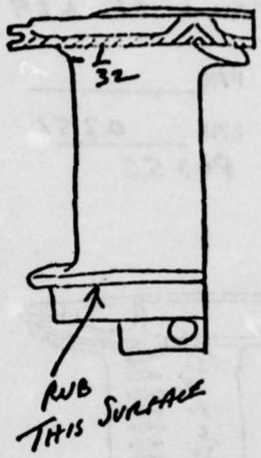
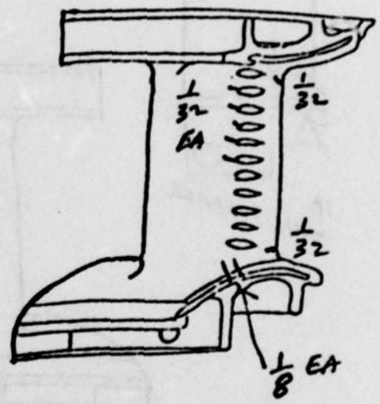
S/N C01423
POS 53

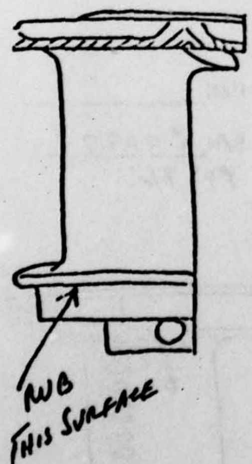




P/N ________

S/N 02323
POS 19





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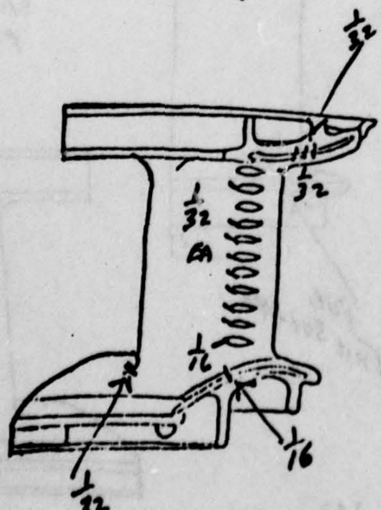
S/N 2134
POS 49



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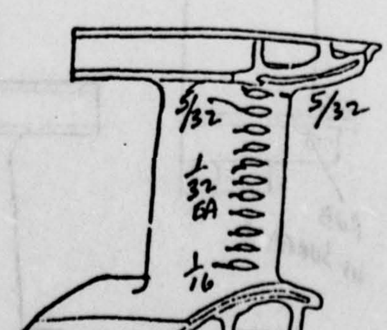
S/N C00424
POS 32

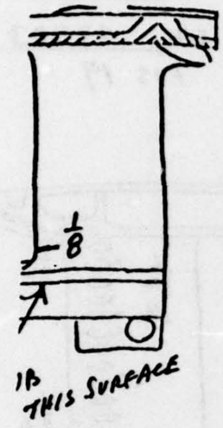


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

It 142163 TD 2 Inspector RW Fisher Date 4-21-78

VANES ARE DETAILS OF 6894686 ASSYS.



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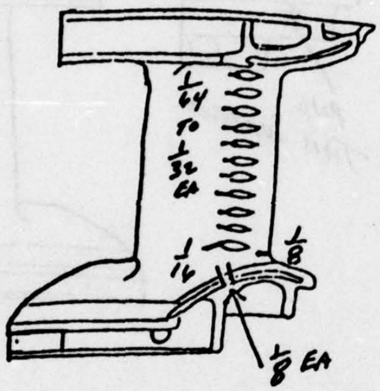
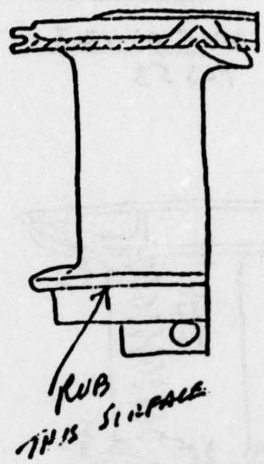
S/N 0351

POS 55





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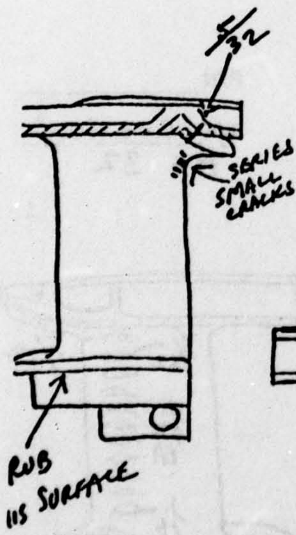
S/N 01416

POS 9



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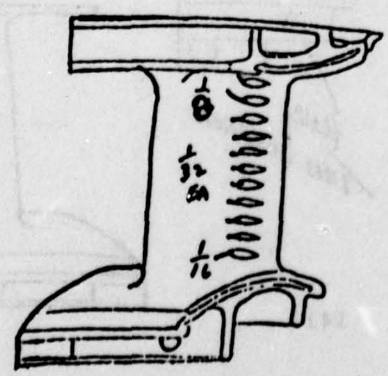
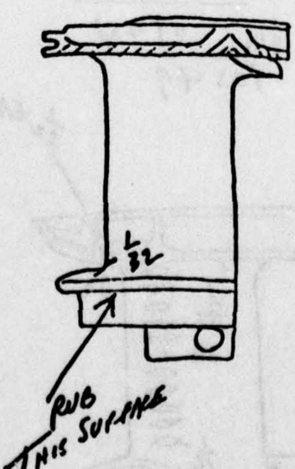
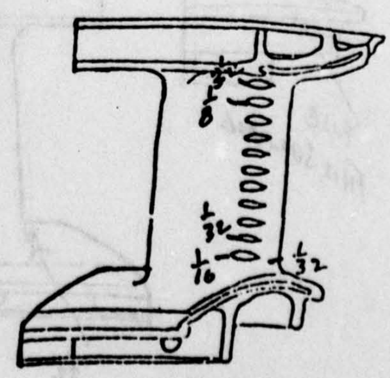




P/N ______

S/N C00274

POS 36

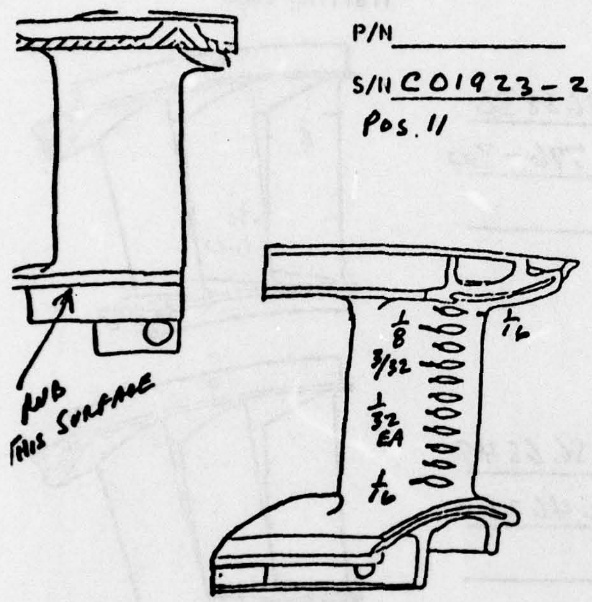


EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142 163 TD 2 Inspector RW Fisher Date 4-21-78

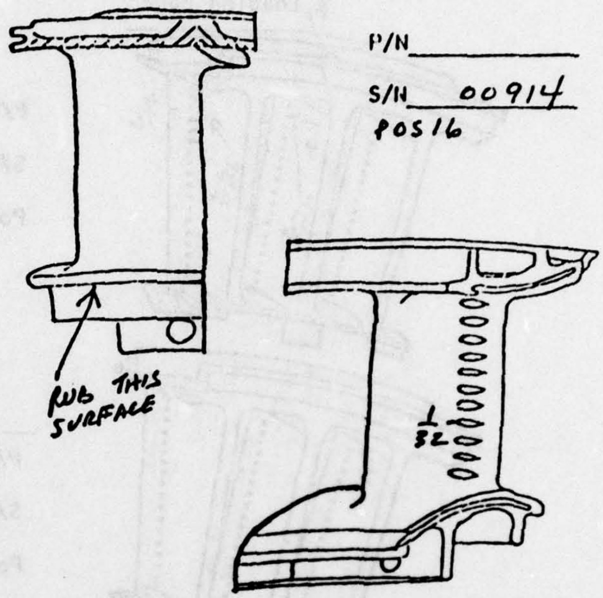
VANES ARE DETAIL OF 6894686 ASSYS



P/N ____________

S/N C01923-2

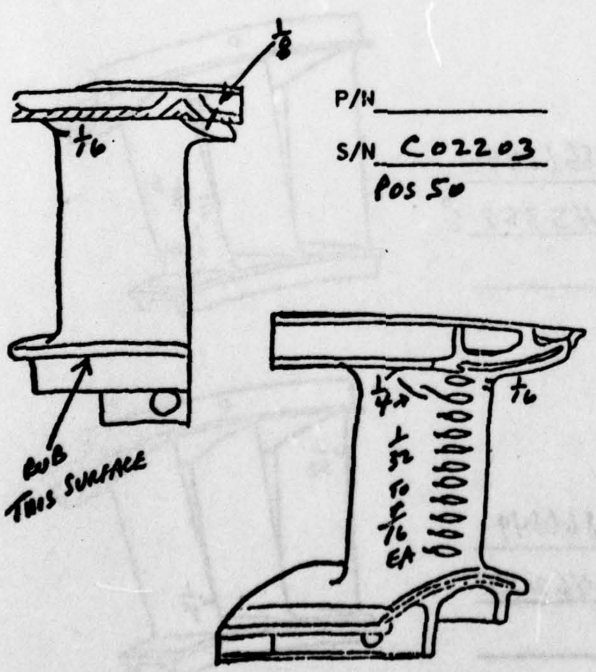
POS. 11



P/N ____________

S/N 00914

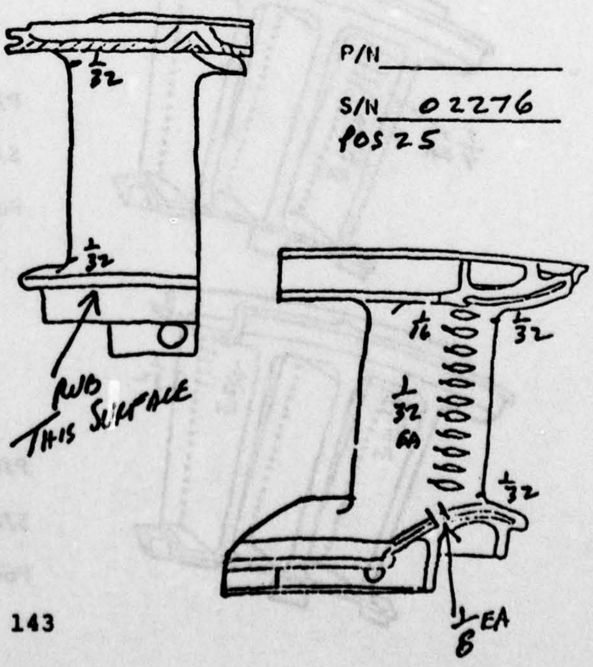
POS 16



P/N ____________

S/N C02203

POS 50



P/N ____________

S/N 02276

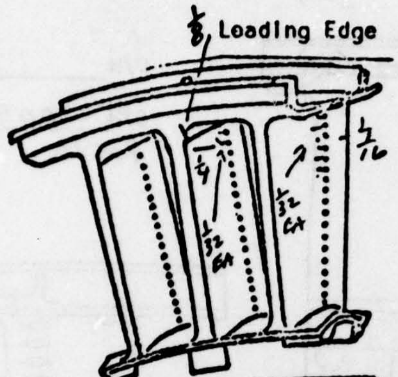
POS 25

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

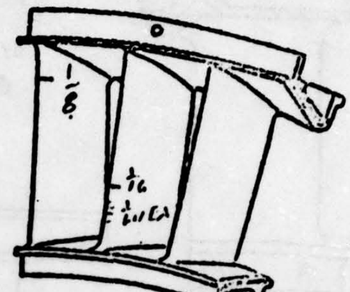
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

Unit 142163 T.D. 2 Inspector [illegible] Date 4-24-78

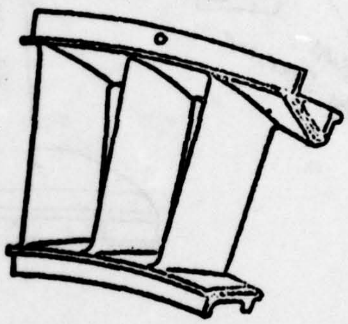
Leading Edge | Trailing Edge

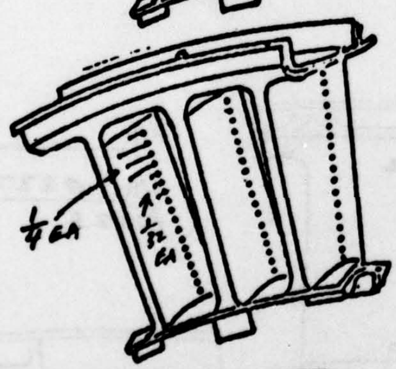


P/N 6868836
S/N 776-30
Pos.________

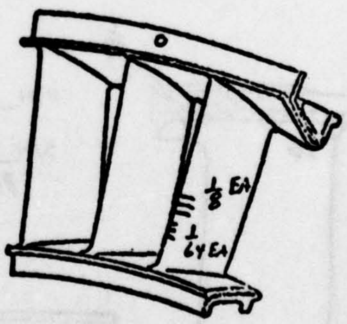


P/N 6866849
S/N C46260
Pos.________

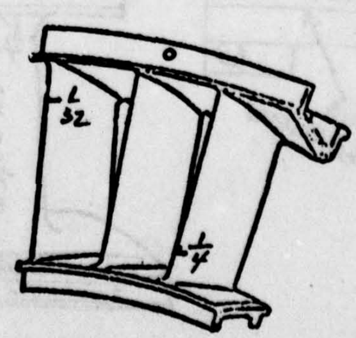




P/N 6866849
S/N C43358 ?
Pos.________



P/N 6866849
S/N C46285
Pos.________

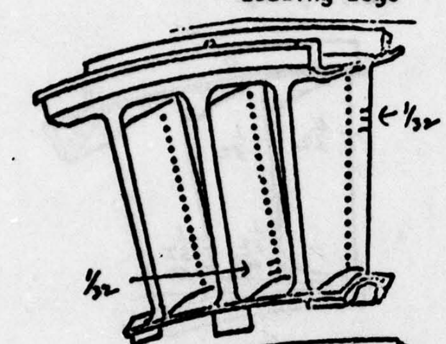


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

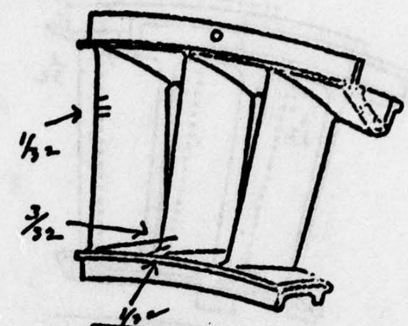
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

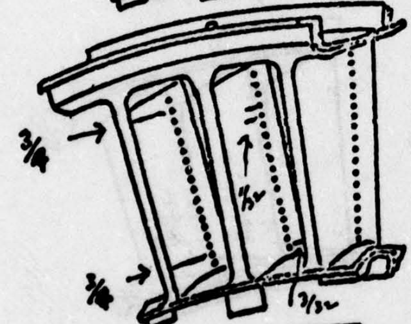
Unit 142163 T.D. 2 Inspector DUCKETT Date 4-25-78

Leading Edge Trailing Edge

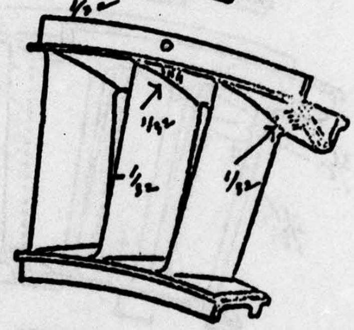


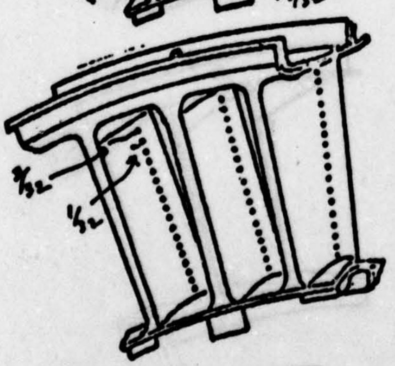
P/N 6866849
S/N C 49065
Pos.



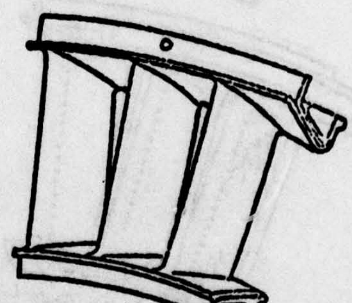


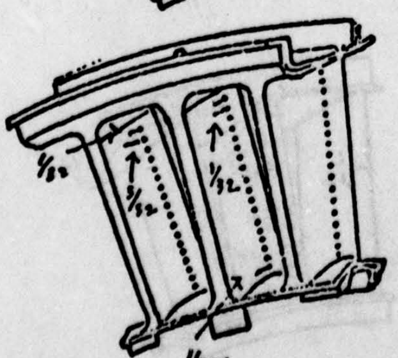
P/N 6866849
S/N C 48055
Pos.



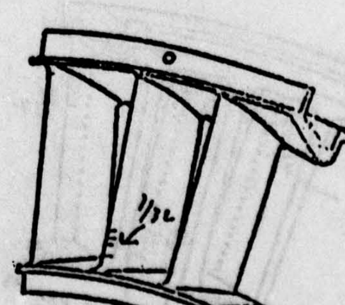


P/N 6866849
S/N C 49423
Pos.





P/N 6866849
S/N C 49592
Pos.



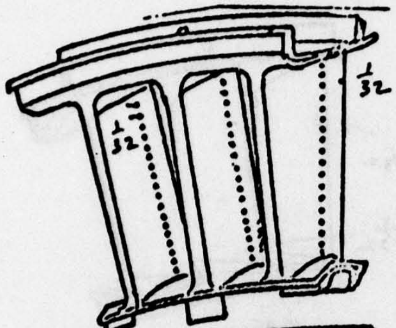
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE. VANE ASSY Ref:

Unit 142163 T.D. 2 Inspector A. Fisher Date 4-25-78

Leading Edge

Trailing Edge



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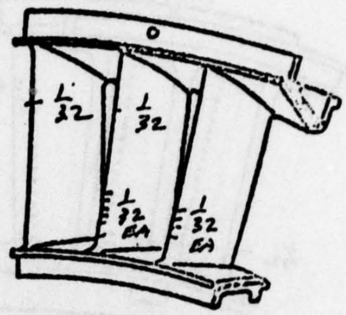

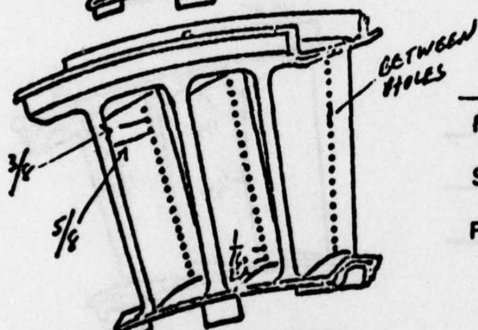

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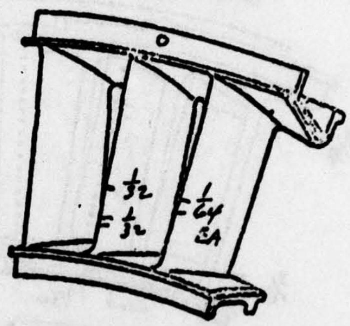

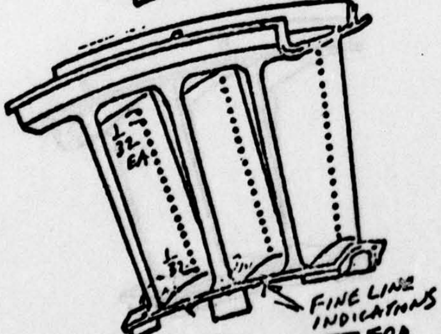

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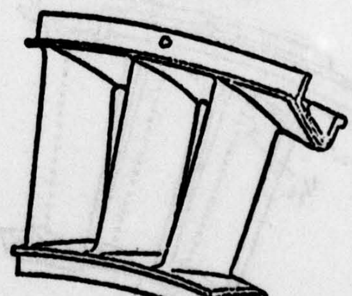

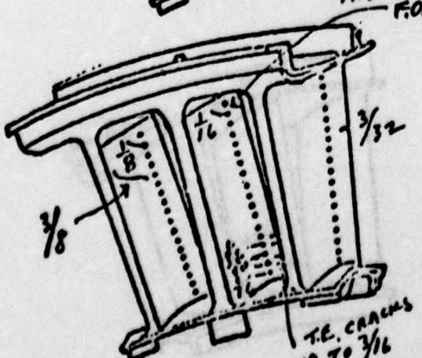

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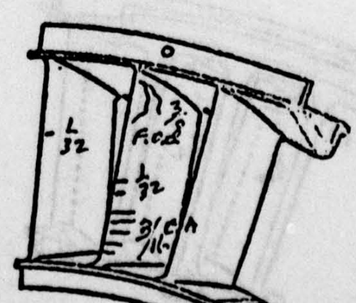
Pos.________

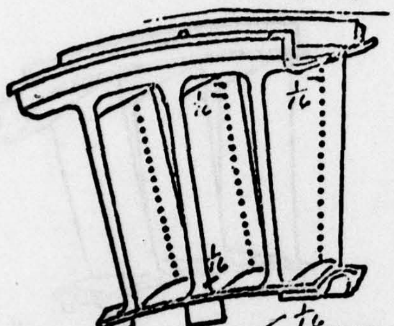


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

Unit 142163 T.D. 2 Inspector R.W. Fisher Date 4-24-78

Leading Edge | Trailing Edge



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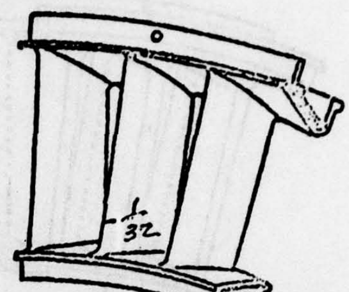

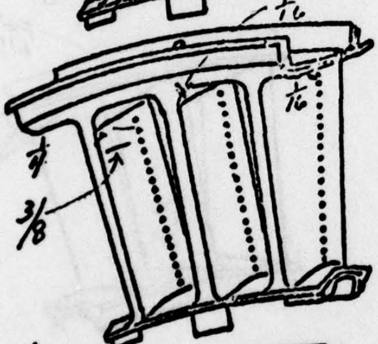

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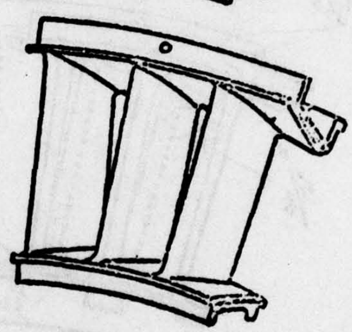

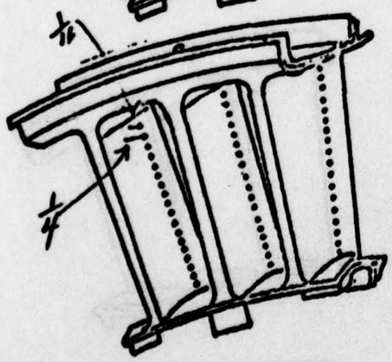

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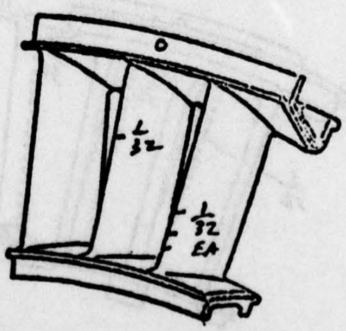

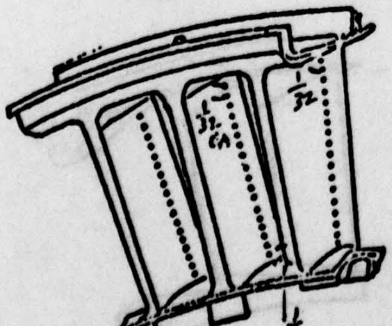

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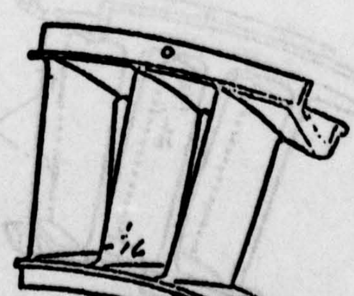
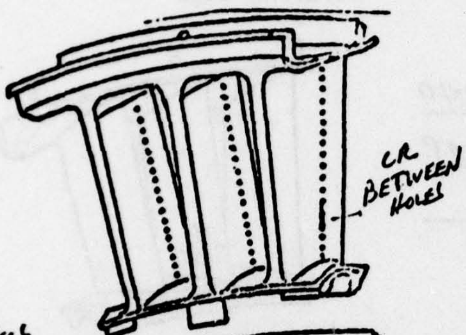


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

Unit 142163 T.D. 2 Inspector RwFisher Date 4-24-78

Leading Edge Trailing Edge



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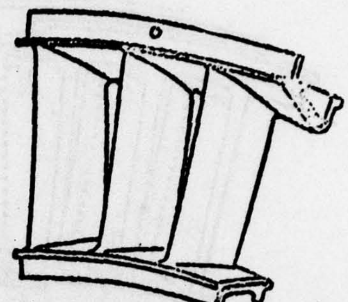

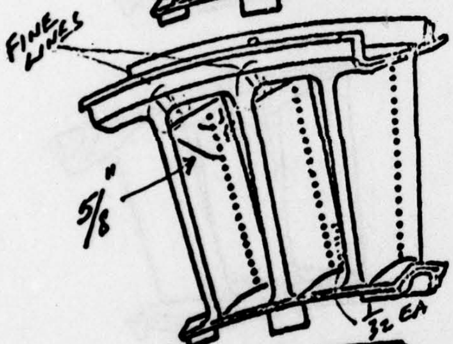

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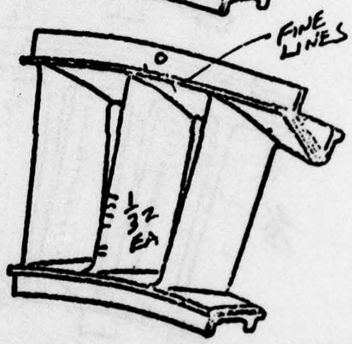

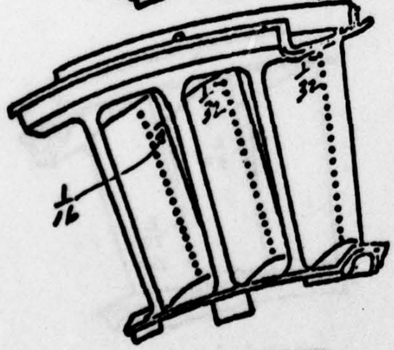

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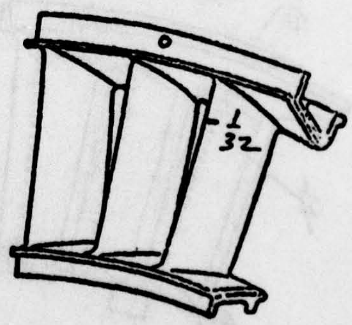

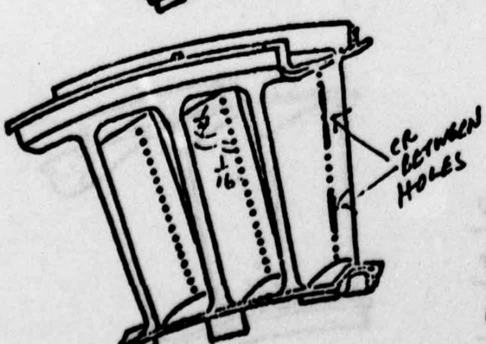

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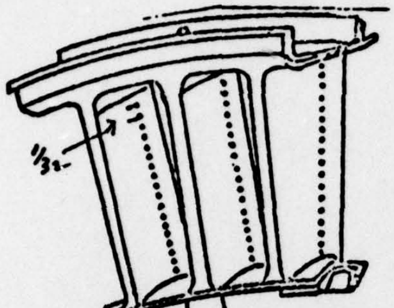
S/N C49475
Pos.________

EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

Unit 142163 T.D. 2 Inspector DUCKETT Date 4-25-78

Leading Edge | Trailing Edge



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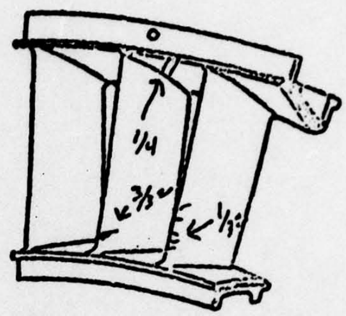
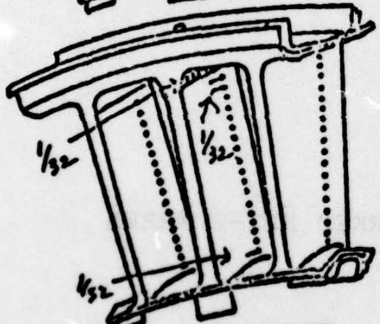
Pos.

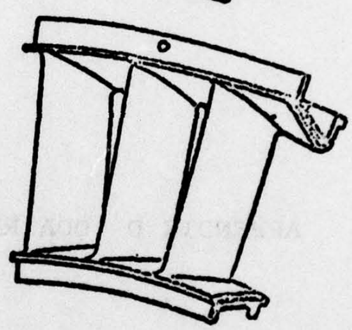




P/N 6866849

S/N C 48482

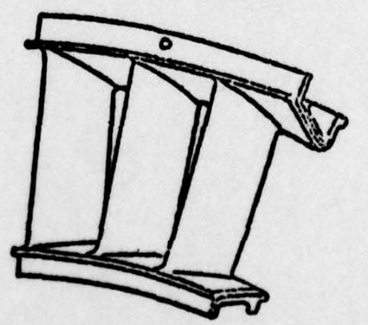
Pos.

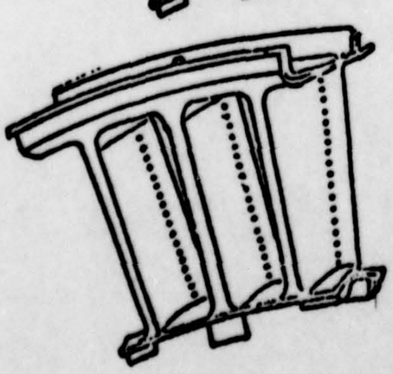


P/N

S/N

Pos.

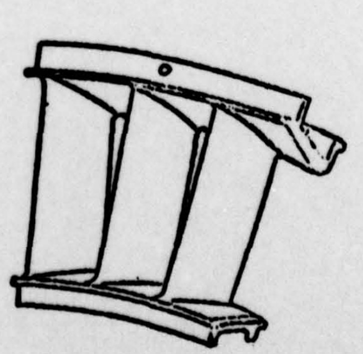




P/N

S/N

Pos.



APPENDIX D DDA RECOMMENDATION ON REWORKED HPT-2 WHEEL

R. May
AFAPL/TBA

Detroit Diesel Allison
Division of General Motors Corporation

DAYTON ZONE OFFICE FILE
MAR 1 . 19
SUBJECT

Indianapolis Operations
P. O. Box 894
Indianapolis, Indiana 46206
Phone: (317) 244-1511
Cable: GM COMM IND A

February 28, 1978

THO-248L-REH

Headquarters
Naval Air Systems Command
1421 Jefferson Davis Highway
Arlington, Virginia 20360

Attention: AIR-5361

Via: DCASPRO

Subject: Evaluation of Field Reworked TF41 HP-2 Turbine Wheel, P/N 6861135, S/N 10198

Reference: (a) EPD 4.13 (Contract F33657-77-C-0108)
(b) THO-1226L-REH dated November 5, 1976
(c) THO-1009L-JWR dated September 20, 1976

HP-2 Turbine wheels with crack indications on the face and extending along the root radius were first reported in mid-1976. Exhibits were returned to this Contractor who determined the cause was handling damage. Investigation results were reported via References (b) and (c). Due to this distress expanded rework procedures and limits were developed. The initial release of the expanded rework allows an additional 250 hours maximum service life.

The subject wheel was reworked at NARF JAX and returned to DDA for rework evaluation including engine testing. The test objective was to run the returned wheel in an Accelerated Mission Test (AMT) and resonance endurance. Two cracked serrations were not reworked for growth comparison purposes. Testing was conducted in an in-house engine. The wheel accumulated 99 hours - 52 hours of AMT and 47 hours resonance endurance, and then was removed for examination.

Examination of the removed wheel revealed no new crack indications in either the wheel or the blades. The two cracks which were not reworked grew approximately 1/16 inch, which was expected. At the conclusion of this examination the wheel was installed in TF41-A-1 S/N 141163 for additional testing at ASD.

The purpose of the ASD testing was to evaluate a proposal to extend the rework time limit from 250 hours to 450 hours. A total of 143.44 hours were logged at ASD, of which 106 hours was AMT. At 143.44 hours an HP-2 Turbine blade failure occurred. The engine was returned to DDA for investigation.

The investigation revealed both the blade and wheel serrations had failed. Post failure investigation showed fatigue in the area of the reworked wheel serrations. However, it was not possible to determine whether the wheel or blade failed first. The two original cracks not blended grew an additional 1/32 inch during the 143.44 hours. As a matter of information there were a total of sixty-nine reworked serrations on this test wheel. (Reference Attachment A).

In view of the ASD test the rework maximum service life will not be extended at this time, and will remain at 250 hours.

Further evaluation of the rework procedure, on wheels in service, prompted DDA to request additional HP-2 Turbine wheels and blades. Five wheels, which had accumulated approximately 225 hours each, were identified for this program by serial numbers. Four exhibits have been received and are currently under investigation. The findings and any recommendations will be reported in separate correspondence.

The exhibit wheel will be returned to the Government Property Room, tagged Scrap, for disposition.

This is considered closing action on the subject investigation.

Very truly yours,

L. O. Davidson, Service Manager
Gas Turbine Engines

REH/vlh

cc: OCALC (MMPR), OCALC (MMPMA), OCALC (MMPRE), OCALC (MMPRT), NAVAIR (AIR-4113), ASD/YZS41, NARF JAX (Code 330), NARF JAX (Code 430), NAVSAFECEN (Norfolk Code 1237), NAVWPNENGSUPPACT (Code ESA 44)

bcc: H. C. Hensley, G. H. Mayo, D. L. Webber, J. Duke, R. C. White, G. D. Thompson, R. G. Pickering, J. R. Black, R. Feldt, All Zones, T. C. Mauch (ZZ 2003), RCR 47F519, Subject 4b, All TF41 Reps & Project Desks

APPENDIX E TEST PLAN

TEST PLAN

AIR FORCE AERO PROPULSION LABORATORY

4 OCT 1977

1. TITLE: Accelerated Mission Test (AMT) of a TF41 with Block 76 hardware.

2. JON: 30661236

3. PROJECT ENGINEER: Robert J. May, Jr. TBA 54830

4. PROJECT TEAM:

Donald P. McErlean	TFA	52266
Kenneth N. Hopkins	TBC	55974
Doretta Holland	TFIC	55636

5. CONFIGURATION: Engine Type - TF41-A-1

Serial Number - 141163

Special Features - Reworked HP-2 turbine wheel

- Block 76 hardware

#6 bearing cast support

HPT-1 cast blades

HPT-1 bull nose vanes

#5 bearing rear seal deletion

HPC 4-5-6 eiffel tower vanes

HPC-1 blades

fuel manifold

NL anticipator

HPT-1 lockplate damper

viton wills ring

6. FACILITY: "D" stand, sea level engine test facility, AF Aero Propulsion Laboratory.

7. FUEL/LUBES: FUEL: MIL-T-5624, JP4

LUBE OIL: MIL-L-7808. See Hoover Smith, SFL, 54667 for a particular drum of MIL-L-7808 to be used for this test in D-bay. It will be Humble 0-77-3.

8. TEST OBJECTIVES:

8.1 Establish durability characteristics of a TF41 with "Block 76" modifications.

8.2 Document overall engine performance deterioration of a TF41 with "Block 76" hardware modifications and attempt to isolate major contributions to engine deterioration.

8.3 Document burner outlet temperature profile changes due to engine deterioration.

8.4 Demonstrate durability of the proposed HP-2 turbine wheel serration rework.

9. INSTALLATION:

9.1 Install engine in "D" bay according to standard TF41 procedures.

9.2 Instrument as specified in instrumentation section of this plan.

9.3 Install tailpipe and exhaust nozzle.

9.4 Install TF41 airmeter bellmouth and screen.

9.5 Connect power lever to automatic throttle control and use standard throttle rigging of 15-18° at idle and 65-68° at intermediate power. Refer to TO 2J-TF41-3 for specific details.

9.6 Service engine with oil provided by SFL.

9.7 Take a 1 pint sample of oil (from oil drum) to SFL.

9.8 Provide bleed take-off pipe for 11th stage HP compressor bleed ports. The amounts of bleed are:

HPC-11 1.5 lbm/sec

9.9 Check all instrumentation for current calibration data and recalibrate as necessary.

10. **INSTRUMENTATION:**

The following list describes the instrumentation requirements for the AMT cyclic test on engine S/N 141163.

10.1 Engine inlet temperature

10.2 Engine inlet pressure

10.3 Bellmouth static pressure

10.4 Low pressure rotor speed

10.5 High pressure rotor speed

10.6 Turbine outlet temperature

10.7 Fuel flow

10.8 Fuel inlet temperature

10.9 Low pressure and intermediate pressure compressor discharge pressure (dual probe).

10.10 Low pressure and intermediate pressure compressor discharge temperature (dual probe).

10.11 High pressure compressor discharge static pressure

10.12 High pressure compressor discharge temperature

10.13 Fuel manifold pressures, pilot and main.

10.14 Low pressure turbine outlet pressure.

10.15 Main oil ΔP

10.16 Engine main oil pressure

10.17 Low pressure cooling air outlet temperature

10.18 Engine vibration

front compressor (vertical) - front flange top

rear compressor (vertical) - fuel manifold boss, top

turbine (near vertical) - LP turbine oil tube boss, bottom

10.19 IGV position

10.21 Power lever position

10.21 Accessory bleed air temperatures, total pressures and static pressures for the HPC 11th stage.

10.22 Engine oil inlet temperature

10.23 Engine thrust

10.24 Temperature limiter amplifier current

10.25 Junction box temperature

10.26 Exhaust gas temperature rake

10.27 Dry bulb temperature

10.28 Wet bulb temperature

11. SPECIAL REQUIREMENTS:

11.1 Continuous recording of the following parameters is required:

- engine inlet temperature
- turbine outlet temperature
- high pressure rotor speed
- low pressure rotor speed
- fuel flow
- temperature limiter amplifier current

12. OPERATING LIMITS:

The engine operating limits are those applicable to any TF41 engine and are spelled out in TO 2J-TF41-6. The operating limits that are entered in the control computer should be coordinated with the TF41 test project team.

13. STANDARD PROCEDURES:

This test will be conducted according to "D" bay standard operating and emergency procedures as outlined in the operators manual. The TF41 prestart checklist will be complied with before the initial start of the day. In addition, the following procedure will be followed:

13.1 Record all start and stop data in log book, including reasons for shutdown.

13.2 No control system or operating limit adjustments shall be made during this test without the specific approval of the project engineer or other team member in his absence.

13.3 Take care to note in the engine log all incidents of the run such as overspeeds, overtemperature, leaks, vibrations, irregular functioning of the engine, facility or instrumentation, smoking or sparking and describe any corrective action taken.

13.4 Once each working day, thoroughly inspect the engine and test equipment for leaks, loose bolts and fittings, visual cracks or impending failures etc, including visual inspection of inlet and turbine. Complete other prestart checklist requirements. Monitor the main oil filter and fuel filter popout switches. Make an entry in the engine log stating if the popout switches were in or out.

13.5 Daily record specific gravity of the fuel and reference temperature in the engine log. Enter these values in the fuel flow meter algorithm.

13.6 Oil servicing shall be in accordance with current TF41-A-1 instructions. Maintain daily log of oil added and oil consumption during the entire test.

13.7 Log all maintenance, planned inspections, boroscope inspections, etc.

13.8 The low pressure compressor and intermediate pressure compressor pressure and temperature instrumentation should be removed during the cyclic testing portion of this test. This instrumentation should be installed only during power calibrations.

13.9 The exhaust gas temperature rake should be installed in the tailpipe only during power calibrations and not during cyclic testing.

13.10 A data point should be recorded after the daily initial start at idle and half way through the 6 minute flat at intermediate power near the end of each "A" cycle.

13.11 Power calibration and exhaust gas surveys should be run with the 11th stage bleeds blocked off.

13.12 The engine should be allowed to stabilize 5 minutes before recording power calibration data.

13.13 The desired tolerance on speed settings during the "automatic" portion of the test shall be $\pm$ 50 rpm NH ($\pm$ 0.4%)

13.14 Once every four hours measure and record barometric pressure, wet bulb temperature and look up vapor pressure from the appropriate curve.

13.15 Check oil level after every four "A" cycles or more often if oil consumption is running abnormally high.

5

13.16 Monitor starter oil temperature during all motoring of the engine. The starter oil temperature should not exceed 300°F.

13.17 Thoroughly wash inlet FOD screen when total pressure drop exceeds 8 inches of H20.

13.18 Rotor coast-down speeds need only be recorded when the oil level is to be checked and for the final shutdown each day.

13.19 Maintain a log of total engine time, total AMT time, and the number and types of cycles that have been run.

13.20 The 11th stage bleed orifice plate will be changed to vary the bleed flow rate allowing operation at higher turbine temperatures as the ambient temperature decreases. Changes in bleed will be made only when the test engineer directs.

13.21 Provide a fuel sample to Ron Butler for a heat of combustion analysis everytime fuel from a new fuel tank is used.

14. INITIAL ENGINE/FACILITY CHECKOUT:

The following procedures should be followed during the initial running of the engine after installation in the test cell:

- motor the engine for at least 30 seconds on the starter
- start the engine and stabilize at idle for 5 minutes
- check all instrumentation readings
- if the facility and engine operation appear normal perform a walk around inspection, checking for leaks, loose fittings etc.
- if there are no discrepancies make a slow accel to 85% NH and stabilize, checking all engine and facility parameters
- if the facility and engine operation appear normal, slowly accel to 90% NH, stabilize, and check all engine and facility parameters.
- if the facility and engine operation appear normal, slowly accel to intermediate power, stabilize, and check all engine and facility parameters.
- perform a slow decel to idle and stabilize.
- if the facility and engine operation appear normal, perform a snap accel to intermediate, stabilize, and then a snap decel to idle.
- if no engine or facility discrepancies have been discovered up to this point, continue with the test plan performing the engine functional checks described in the following section. If problems have been identified shut down, make the necessary repairs, and then complete the remaining steps of this section.

15. ENDURANCE TEST:

The engine will be trimmed and set up before delivery to AFAPL by Allison.

15.1 Engine Functional Check (every 50 hours) see TO 2J-TF416, para 10-35 and Table 10-4.

15.1.1 Check IGV ram closing schedule. Determine that the attached schedule is satisfied (IGV = +33° and +7).

15.1.2 Check NL governor with pulldown tool according to TO 2J-TF41-6, para 10-63.

15.1.3 Check T5.1 pulldown according to TO 2J-TF-41-6, para 10-66.

15.1.4 Check P3 limiter according to TO 2J-TF41-6, para 10-64.

15.1.5 Check NH governor according to TO 2J-TF41-6, para 10-59, 10-60, 10-62.

15.1.6 Check ACU and DCU according to TO 2J-TF41-6, para 10-70, 10-71, 10-72, 10-73.

15.1.7 Check mass flow limiter using the T1 simulator and according to TO 2J-TF41-6, para 10-60.

15.2 High pressure rotor speed and power lever calibration (every 50 hours).

15.2.1 Stabilize 5 minutes at each NH speed listed

10,000 ± 100 rpm

10,500 ± 100 rpm

10,900 ± 100 rpm

11,300 ± 100 rpm

11,700 ± 100 rpm

12,100 ± 100 rpm

12,300 ± 100 rpm

15.2.2 Plot NH (rpm) versus power lever angle. Determine power lever angle corresponding to the following speeds and provide this information for input into the automatic throttle control.

7

NH (rpm)	%rpm	PLA
10,332	80	
10,589	82	
10,977	85	
11,235	87	
11,364	88	
11,623	90	
12,010	93	
12,140	94	
12,269	95	

15.3 Performance calibration (every 50 hours)

15.3.1 Blank off bleed ports

15.3.2 Install low pressure compressor and intermediate pressure compressor discharge instrumentation.

15.3.3 Stabilize for 5 minutes at the following levels of corrected thrust:

idle

7000 ± 200 lb

8000 ± 200 lb

9000 ± 200 lb

10,000 ± 200 lb

11,000 ± 200 lb

12,000 ± 200 lb

13,000 ± 200 lb

14,000 ± 200 lb

intermediate

15.4 Exhaust gas temperature survey

15.4.1 Blank off bleed ports

15.4.2 Install thermocouple rake

15.4.3 Stabilize for 5 minutes at intermediate power and record data.

15.4.4 Shut down

15.4.5 Rotate tailpipe one bolt hole and repeat.

15.4.6 Repeat twice until a total of 4 data points have been obtained.

15.5 Scheduled Inspections

15.5.1 Perform engine boroscope inspection of the hot section after each 100 hours of AMT testing.

15.5.2 Standard field service inspections shall be made and documented throughout the test. Reference TF41 Service and Operation Manual, Allison Publication Nr 1F2, 1 March 1974, Section 7.

- conduct 50 hours phase inspection

- conduct 100 hour phase inspection

- conduct 150 hour phase inspection

- conduct 200 hour phase inspection

15.5.3 Take two 1 pint oil samples immediately after initial servicing and at approximately 25 test hour intervals thereafter. The container will be provided by and the samples should be sent to SFL, Hoover Smith, 54667. SOAP and ferrograph analyses should be run.

15.6 Cyclic testing

15.6.1 The actual test consists of running the engine through a specified number of test cycles, labeled the "A", "B", and "C" cycles. A detailed description of these cycles is included on the attached pages. The test consists of 15 blocks made up of 20 "A" cycles, 4 "B" cycles, and 1 "C" cycle each.

15.6.2 Set the 11th stage bleed at approximately 1.5 lbs/sec (.62" diameter orifice plate) unless the test engineer specifies a different bleed flow rate.

15.6.3 Remove high pressure compressor and intermediate pressure compressor instrumentation.

15.6.4 Remove exhaust gas survey rake

15.6.5 Enter "A" cycle into autothrottle and run 20 cycles.

15.6.6 Enter "B" cycle into autothrottle and run 4 cycles

15.6.7 Enter "C" cycle into autothrottle and run 1 cycle

NOTE: The sequence of "A", "B", and "C" cycles is relatively insignificant. The number of each type of cycle run is important. The sequence may be altered to better fit available test time.

15.6.8 Repeat 14.7.5 - 14.7.7, 14 times performing the required inspections and calibrations etc. Run 5 extra "A" cycles. (This makes for approximately 263 hours of AMT testing)

15.6.9 Upon completion of 263 hours of cyclic testing, remove the engine and return to Allison for a teardown inspection.

CYCLE A

FLIGHT OPERATION

TIME (Min:Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
0:00	:30	Start. Engine and accel to 55%	
0:30	2:00	Engine at Idle pwr	
2:30	:30	Accel to 90% N_H Dbl. datum on	
3:00	2:30	Accel to Intermediate Dbl Datum on	
5:30	1:00	Decel to 85% N_H, Dbl Datum Off	
6:30	2:00	Accel to Intermediate (100% N_H)	
8:30	:30	Decel to 90% N_H	
9:00	:15	Decel to 55% N_H	
9:15	:10	Accel to Intermediate	
9:25	:25	Decel to 93% N_H	
9:50	3:48	Accel to Intermediate, then Decel to 94% (19 Times). Each transient will take 6 sec.	
13:38	:12	Accel to Intermediate, transient to take 6 sec.	
13:50	:30	Decel to 88% N_H	
14:20	:08	Accel to Intermediate	
14:28	:15	Decel to 55% N_H	
14:43	:45	Accel to Intermediate	
15:28	:30	Decel to 88% N_H	
15:58	:08	Accel to Intermediate	
16:06	:15	Decel to 55% N_H	
16:21	:45	Accel to Intermediate	
17:06	:30	Decel to 88% N_H	
17:36	:08	Accel to Intermediate	
17:44	:07	Decel to 85% N_H	
17:51	:35	Accel to Intermediate	
18:26	:15	Decel to 90% N_H	
18:41	:08	Accel to Intermediate	
18:49	:07	Decel to 85% N_H	
18:56	:35	Accel to Intermediate	
19:31	:15	Decel to 90%	

CYCLE A

FLIGHT OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
19:46	:08	Accel to Intermediate	
19:54	:07	Decel to 85% N_H	
20:01	:35	Accel to Intermediate	
20:36	:15	Decel to 90% N_H	
20:51	:08	Accel to Intermediate	
20:59	:07	Decel to 85% N_H	
21:06	:35	Accel to Intermediate	
21:41	:15	Decel to 90% N_H	
21:56	:08	Accel to Intermediate	
22:04	:15	Decel to 55% N_H	
22:19	:35	Accel to Intermediate	
22:54	:30	Decel to 88% N_H	
23:24	:08	Accel to Intermediate	
23:32	:15	Decel to 55% N_H	
23:47	:35	Accel to Intermediate	
24:22	:30	Decel to 88% N_H	
24:52	:08	Accel to Intermediate	
25:00	:15	Decel to 55% N_H	
25:15	:35	Accel to Intermediate	
25:50	1:00	Decel to 88% N_H	
26:50	:08	Accel to Intermediate	
26:58	:07	Decel to 85% N_H	
27:05	:35	Accel to Intermediate	
27:40	:15	Decel to 90% N_H	
27:55	:08	Accel to Intermediate	
28:03	:07	Decel to 85% N_H	

CYCLE A

TIME (Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
28:10	:30	Accel to Intermediate	
28:40	:15	Decel to 90% N_H	
28:55	:08	Accel to Intermediate	
29:03	:07	Decel to 85% N_H	
29:10	:30	Accel to Intermediate	
29:40	:25	Decel to 90% N_H	
30:05	:15	Decel to 55% N_H	
30:20	:10	Accel to Intermediate	
30:30	:05	Decel to 88% N_H	
30:35	6:00	Accel to Intermediate	
36:35	:15	Decel to 55% N_H	
36:50	1:10	Accel to Intermediate	
38:00	:05	Decel to 80% N_H	
38:05	:05	Accel to 87% N_H	
38:10	:05	Decel to 80% N_H	
38:15	:05	Accel to 90% N_H	
38:20	:15	Decel to 55% N_H	
38:35	:30	Accel to Intermediate	
39:05	:05	Decel to 82% N_H	
39:10	:05	Accel to 90% N_H	
39:15	:15	Decel to 55% N_H	
39:30	:30	Accel to Intermediate	
40:00	:05	Decel to 82% N_H	
40:05	:05	Accel to 90% N_H	
40:10	3:19	Decel to 55% N_H	
43:29		Shutdown engine	
45:29		Motor Engine on Starter	
47:59		Start Engine and Accel to Idle	
48:29		Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME: 43 Min. 29 Sec.

CYCLE B

FLIGHT LINE OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
0:00	3:00	Engine at Idle Pwr	
3:00		Shutdown Engine	
5:00		Motor Engine on Starter	
7:30	:30	Start Engine and Accel to Idle Pwr	
8:00	3:00	Engine at Idle Pwr	
11:00		Shutdown Engine	
13:00		Motor Engine on Starter	
15:30	:30	Start Engine and Accel to Idle Pwr	
16:00	3:00	Engine at Idle Pwr	
19:00		Shutdown Engine	
21:00		Motor Engine on Starter	
23:30	:30	Start Engine and Accel to Idle Pwr	
24:00		Engine at Idle Pwr Ready for Next Cycle (A or C depending on schedule).	

TOTAL CYCLE ENDURANCE TIME 10 Min 30 Sec

CYCLE C

GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE; THROTTLE FOR A CIT CONDITIONS
0:00:00	3:00	Engine at Idle Pwr	
0:03:00	3:15	Accel to Intermediate (No DD)	
0:06:15	3:00	Decel to Idle Pwr	
0:09:15	3:15	Accel to Intermediate	
0:12:30	3:00	Decel to Idle Pwr	
0:15:30	3:15	Accel to Intermediate	
0:18:45	3:00	Decel to Idle	
0:21:45	3:15	Accel to Intermediate	
0:25:00	3:00	Decel to Idle	
0:28:00	3:15	Accel to Intermediate	
0:31:15	3:00	Decel to Idle	
0:34:15	3:15	Accel to Intermediate	
0:37:30	3:00	Decel to Idle	
0:40:30	3:00	Accel to 95%	
0:43:30	3:00	Decel to Idle	
0:46:30	3:00	Accel to 95%	
0:49:30	3:00	Decel to Idle	
0:52:30	3:00	Accel to 95%	
0:55:30	3:00	Decel to Idle	
0:58:30	3:00	Accel to 95%	
1:01:30	3:00	Decel to Idle	
1:04:30	3:00	Accel to 95%	
1:07:30	3:00	Decel to Idle	
1:10:30	3:00	Accel to 90%	
1:13:30	3:00	Decel to Idle	
1:16:30	3:00	Accel to 90%	

CYCLE C

GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE)	
ELAPSED	AT		THROTTLE	FOR ALL CIT CONDITIONS
1:19:30	3:00	Decel to Idle		
1:22:30	3:00	Accel to 90%		
1:25:30	3:00	Decel to Idle		
1:28:30	3:00	Accel to 90%		
1:31:30	3:00	Decel to Idle		
1:34:30	3:15	Accel to Intermediate		
1:37:45	3:00	Decel to Idle		
1:40:45	3:15	Accel to Intermediate		
1:44:00	3:00	Decel to Idle		
1:47:00	3:15	Accel to Intermediate		
1:50:15	3:00	Decel to Idle		
1:53:15	3:15	Accel to Intermediate		
1:56:30	3:00	Decel to Idle		
1:59:30	3:00	Accel to Intermediate		
2:02:45	3:15	Decel to Idle		
2:05:45		Shutdown Engine		
2:07:45		Motor Engine on Starter		
2:09:45		Start and Accel to Idle Pwr		
2:10:15	:30	Engine at Idle Pwr Ready for Next Cycle		

TOTAL CYCLE ENDURANCE TIME 2 Hrs 6 Min 15 Sec

APPENDIX F COMPUTER DESCRIPTION

Taylor 1010

The following is a brief description of the Taylor 1010 and its capabilities.

Type	General purpose microprogrammed digital computer
Word Length	16 Bit words
Cycle Time	Full cycle memory time 660 nano-seconds
Instructions	160 instruction set
Memory, core	Single part, 3 wire, 3 dimensional magnetic core
Registers	16 general purpose registers
Arithmetic	Binary, 2's compliment
Instruction Execution Time	Register to register 660 nanoseconds Memory to register 1320 nanoseconds Jump 1361 nanoseconds
Input/Output Transfer rate	Direct memory access 897,800 Words per second
Standard Features	Automatic bootstrap loader Teletype controller Memory protection Hardware priority interrupt I/O bus control logic Power failure/restart Real-time clock Multiply/divide
System Options	Priority interrupt module Buffer interlace controller
Peripherals	Fixed head disk Color display CRT (2) Line printer (2) Teletypes (2) Analog signals Digital signals Card reader Card punch

Standard Software	DAS Symbolic Assembler	Modular 2 pass Assembler
	FORTRAN IV	Modular 1 pass Complier
	TMX	Taylor Real-Time Executive
	COMGEN	Control Modular Generation System
	TABL	Taylor Advanced Batch Language

"D"-Bay Configuration

The "D"-Bay computer system is shown pictorially in Figure 45 and schematically in Figure 46. The following is a list of the functions of each piece of equipment.

Central Processor A. In the engine test mode, System A runs the control programs for the entire system. All monitoring and control is done through this computer.

Bus Switch. Contains the "Watch Dog Timer" which keeps track of I/O execution and triggers a switch to the backup computer if excessive time is taken by the primary computer.

High Speed Memory Link. Transfers the data base in System A core to core in System B at a once-a-second rate.

Analog and Digital Input. Reads voltages, temperatures, status of contacts, etc., in random access mode under program control.

I/O Interface. Converts measurements to digital counts for manipulation by the computer.

Fixed Head Disk. Storage device which contains a copy of all user programs and non-resident software. A copy of the core resident data base is written every second to disk on System A.

TTY1. Communicative teletype for the TMX operating system in A computer.

TTY2. Communicative teletype for the TMX operating system B computer.

Line Printer 1. Process output device which notifies the operator of alarms, status and progress of facility and engine test.

Figure 45 "D"-Bay Control Room

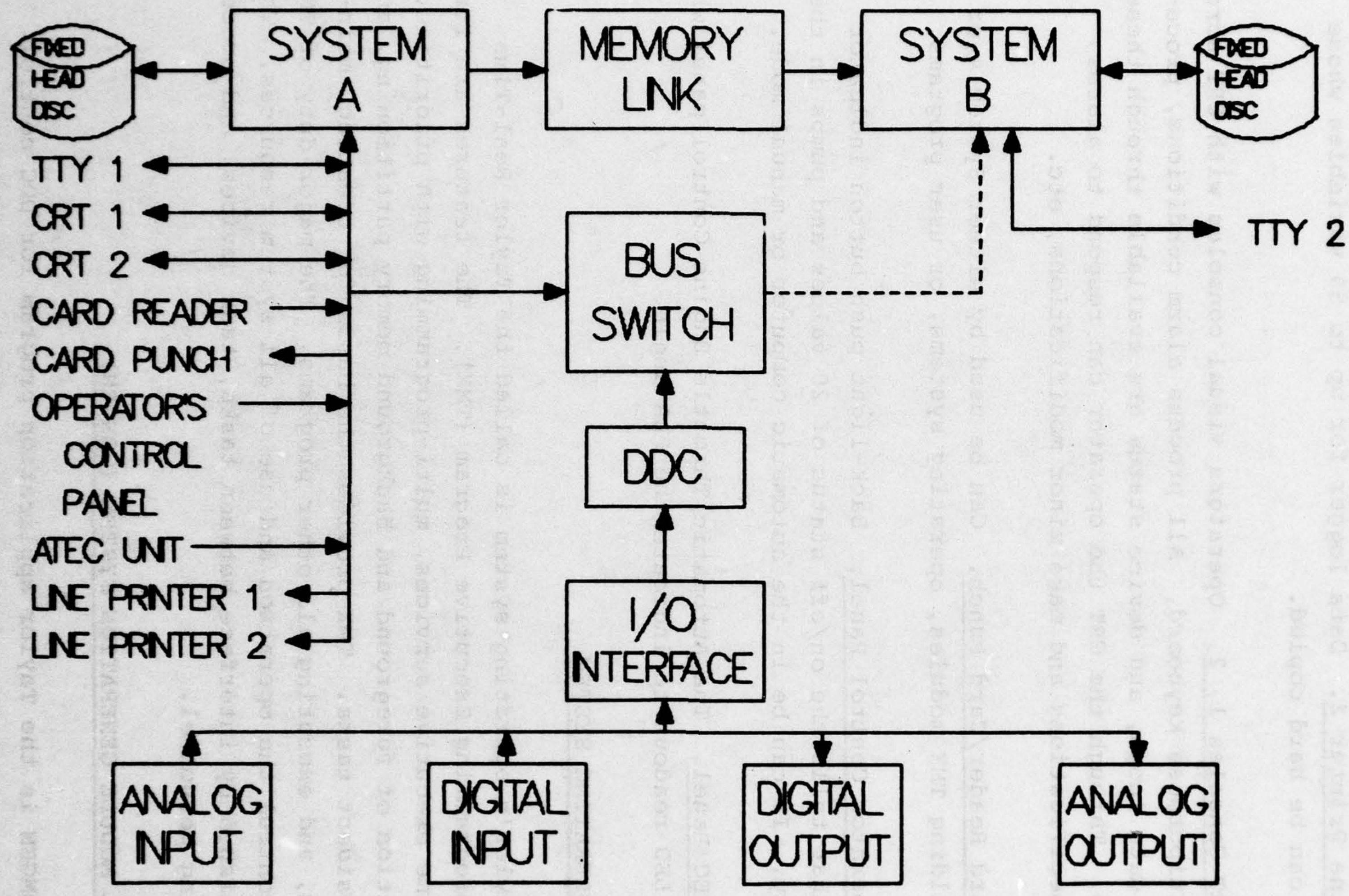


Figure 46 Schematic of "D"-Bay Computer System

Line Printer 2. Data logger for up to 50 variables whose status can be hard copied.

CRT Consoles 1, 2. Operators visual consoles with CRT screen and multipurpose keyboard. All process alarm conditions, procedures, data loops, and device status are available through these screens. Through the CRT the operator can respond to alarms, test specifications and make minor modifications, etc.

Card Reader/Card Punch. Can be used by either System A or B for building TMX modules, operating systems, or user programs.

Operator Control Panel. Back-light push button indicator panel that tells the on/off status of 20 values and pumps in the facility. It can be in the automatic computer or manual mode.

ATEC Panel. The Automatic Throttle Engine Control panel which uses a LED readout to indicate the PLA angle.

BASIC OPERATING SYSTEM

Taylor's operating system is called the Taylor Real-Time Multi-programming Executive Program (TMX). The features are its real-time executive services, multi-programming with priorities, utilization of foreground and background memory partitioning, and core resident tasks. TMX provides the basis for creating, maintaining, and executing all other programs. The major duty of TMX is to control the operation and use of all system resources. This is accomplished by interface between tasks, task devices, and process operating personnel.

CONTROL MODULE GENERATION SYSTEM (COMGEN)

COMGEN is the Taylor application program for DDC control. It provides the basis for handling all continuous variables within the

computer. Basic components include a block processor, a data base, a compiler, an operator's console package, and a message distribution system. COMGEN constructs a series of tables during its initial data base builds and uses them to determine the required control action. Some of the major functions of COMGEN are data acquisition, data integrity alarm, data linearization and conversion, set point and direct digital control, in either positional (full value) or velocity (incremental) manner, and graphic display handling and recording (trending).

The base for COMGEN is the concept of a data loop. Simply stated, a loop is a module of information about a measured parameter. The properties of each loop are contained within a prescribed data structure called a block. There are four types of blocks: input, process, control, and output. Every variable monitored by COMGEN must have an input block. This block receives the measured signal, and refines it by linearized compensation, filtering, etc., based on the defined properties. An input block requires the following information:

- Variable identity - loop ID or name.
- Frequency that the variable must be measured
- Type of input (voltage, frequency).
- Point number where connected to the hardware multiplexer.
- Hardware multiplexer.
- Gain at which multiplexer is to be read.
- Minimum value of raw signal to be allowed.
- Maximum value of raw signal to be accepted as in range.
- Algorithm to be used in converting voltage to a variable.
- Engineering unit (zero and span).
- High limit.
- Low limit.
- Rate limit.
- Logging code

Process blocks are used for special conditioning of an input block results, i.e., averaging a number of variables, selecting a higher or lower variable, or performing algebraic manipulation. Control blocks are used to control continuous variable functions. This is accomplished by calculating a control output correction variable. The output blocks are used to send a corrected variable to an external actuator (Figure 47).

All the block descriptions are initially configured from card input. Modification to the data is rather simple since the majority of the block information in the data base is available to the operator via the CRT. Limits, values, spans, etc., can be changed to reflect desired processing needs. Through the CRT, the operator also has access to each loop description, device alarms, loop alarms, loop status or results, and trending.

COMGEN scans its loops once a second and refreshes the CRT to reflect changes. The test operator has immediate access and knowledge of the parameters needed to run the facility and the engine.

TAYLOR ADVANCED BATCH LANGUAGE (TABL)

In the Taylor 1010 system, TMX is responsible for controlling the utilization of the computer resources; COMGEN is the interface between the instrumentation and the operator, and TABL controls the sequence of events in the D-Stand operation. This unique batch user's language uses a series of tables and COMGEN results to progress through the five sequences or procedures in the "D"-Bay operation. These sequences are known as Facility Start-Up, Engine Start-Up, Engine Run, Engine Shutdown, and Facility Shutdown. Each of the procedures is accomplished by a series of TABL instructions designed to bring the facility and the engine to the desired operating state.

TABL provides a table called the "Active Recipe" from which the engine is actually run in the semi-automatic mode. The "Active Recipe" contains the steps of the test cycles which the engine is

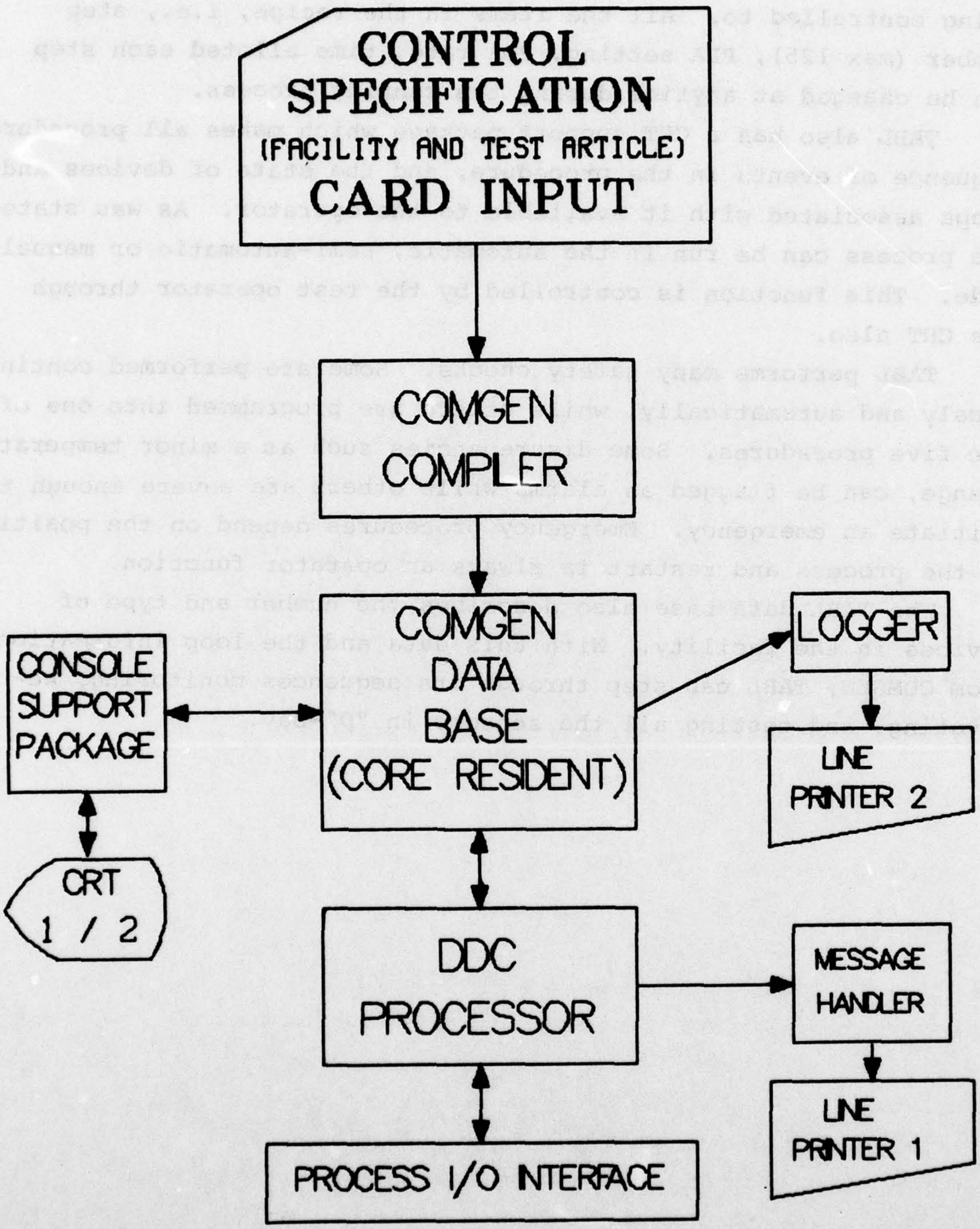


Figure 47 COMGEN Control System

being controlled to. All the items in the recipe, i.e., step number (max 125), PLA setting, PLA rate, time alloted each step can be changed at anytime during the running process.

TABL also has a CRT support package which makes all procedures, sequence of events in the procedure, and the state of devices and loops associated with it available to the operator. As was stated, the process can be run in the automatic, semi-automatic or manual mode. This function is controlled by the test operator through the CRT also.

TABL performs many safety checks. Some are performed continuously and automatically, while others are programmed into one of the five procedures. Some discrepancies such as a minor temperature change, can be flagged as alarms while others are severe enough to initiate an emergency. Emergency procedures depend on the position in the process and restart is always an operator function.

The TABL data base also describes the number and type of devices in the facility. With this data and the loop information from COMGEN, TABL can step through its sequences monitoring, activating, and testing all the sensors in "D"-Bay.

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